Airplane Lofting

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AIRPLANE LOFTING

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PREFACE

The use of the mold loft is well known to shipbuilders. To the aircraft industry it is new. And to the aircraft industry are coming many students who seek much in the way of technical literature on aircraft construction. That these students may have a basis for further information on laying off airplane structures, this book is written.

There is a dearth of data published on the practical procedures of the loftsman. Wherever possible, practical considerations have governed the presentation of the material in this volume. Much may have been omitted that would be of value to those following the loftsman's profession. However, because books do best if they make men think for themselves, this volume can be regarded as a counterpart to the education one receives by working in the mold loft itself.

The airplane manufacturers who have led the field in photographic reproduction as applied to the mold loft have made it possible to include herein the features of these new methods that have greatly advanced the general process of lofting. Continued publication of data on their experiments and developments will give hope to those seeking the ideal in this process.

Many references have been freely used in preparing this book. Without these, the task might have been an impossible one. To those individuals who have rendered valuable assistance in the preparation of this volume, the author expresses his appreciation.

William Nelson.

Philadelphia, Pa.,
October, 1941.

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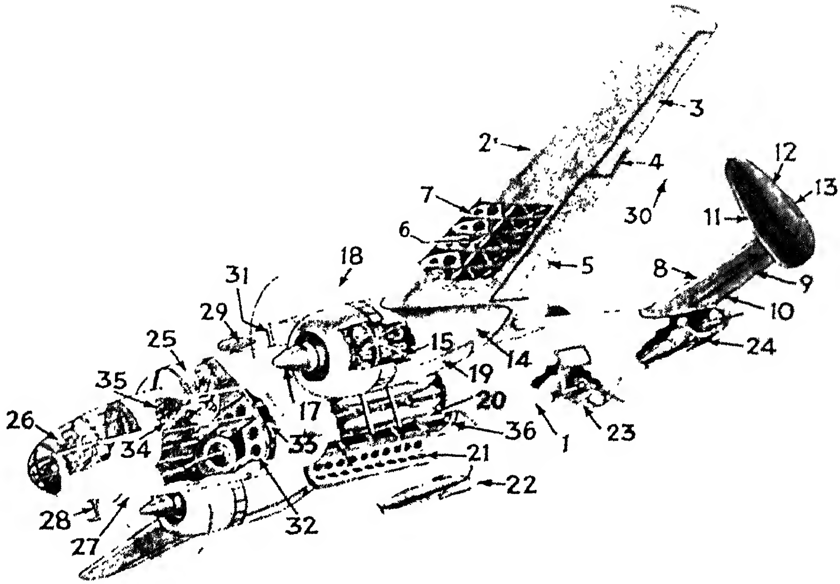

PLATE I.--Sectional view military airplane.

1. Fuselage
2. Wing
3. Aileron
4. Aileron Tab
5. Flap
6. Main Wing Spar
7. Wing Rib
8. Stabilizer
9. Elevator
10. Elevator Tab
11. Fin
12. Rudder
13. Rudder Tab
14. Engine Nacelle
15. Engine Mount
16. Engine
17. Spinner
18. Propeller
19. Main Landing-gear Door
20. Stored Bombs
21. Bomb-bay Doors
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23. Gun Station
24. Gun Station at Tail
25. Pilot's Compartment
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27. Nose-wheel Door
28. Pitot Tube
29. Direction-finder Loop
30. Radio Antenna
31. Antenna Mast
32. Fuselage Bulkhead
33. Stringer
34. Rudder Pedals
35. Instrument Panel
36. Fuselage Frame

AIRPLANE LOFTING

CHAPTER I

OUTLINE OF AIRPLANE CONSTRUCTION

Definitions. Laying out work in the mold loft as applied to the airplane is a direct growth from similar processes performed in building ships. Long before the present day, it was found that the mold loft served a useful function in constructions where parts with intricate form had to be fitted together to build a ship. Lofting as applied to aircraft is a direct inheritance from the shipbuilding industry; and although it came of age long before this, its application to airplane construction has been of recent origin.

Airplane lofting requires terms peculiar to the airplane and expressions common to airplanes and to the mold loft. Because these terms and expressions are frequently unusual, it is desirable to give definitions of the most important of them so that they shall be clearly understood. It is convenient to divide them into those applied only to aircraft and those commonly used in the mold loft.

Aeronautics has developed a terminology of its own which has no parallel in the literature relating to machines or vessels. As far as possible, it has drawn on many lines of endeavor to give expression to its own peculiarities. With the flying boat a measure of conformance is introduced, in that the nomenclature draws on ship terms to connote like parts and functions. The loftsman is interested in special aspects of definitions as applied to the airplane. In order to avoid confusion, we have limited the definitions given to those special aspects.

Airplanes are classified as *landplanes*, *seaplanes*, and *amphibians*. Seaplanes include flying boats. Seaplanes may be single or twin float types, or they may have single or twin hull arrangements.

An airplane consists of the parts shown in Plate I. These parts divide themselves into the *body group* (fuselage, landing gear,

etc.), the *wing group*, the *tail group*, and the *power-plant group* (engine, propeller, tanks etc.). The *structure* is what the name implies. The *fixed equipment* includes instruments, armament, radio, and similar installations.

The *gross weight* of an airplane includes the *weight empty* (*i.e.*, less fuel, ammunition, crew, cargo, etc.) and the *useful load.* The *useful load* includes fuel, crew, cargo, ammunition, passengers, etc. The *pay load* consists of cargo and passengers only.

The *performance* of an airplane includes maximum speed, landing speed, climbing rate, ceiling (altitude), and like performance characteristics for that airplane.

The airplane is a transport machine heavier than air, which gets *lift* by the reaction of air against its wings. The *fuselage* is the body forming the structure in which equipment is installed and to which wings, tail surfaces, and power plant are secured. The *wing* is the airfoil form from which the airplane gets substantially all its lift. The *landing gear* supports the weight of the airplane when it is in contact with the ground. The *hull of a flying boat* acts as float landing gear and fuselage in combination.

The airplane has three axes. The *longitudinal axis* in the plane of symmetry parallel to the propeller thrust line is fore and aft. This is also the level axis. Movement about this axis is *roll.* The *lateral axis* is athwartships perpendicular to the longitudinal axis. Movement about this axis is *pitch.* The *normal axis* through the center of gravity is perpendicular to the other two axes. Movement about the normal axis is *yaw.*

In Fig. 1, the *length over all* L, *the height*, and *the span* W of an airplane are self-evident. The angle $XX'A$ is the *landing angle.* MON is the *angle of attack.* PQR is the *dihedral angle.* SU is the *sweepback.*

The forward part of an airplane is its *nose;* the afterpart, its *tail. Inboard, outboard, forebody, afterbody, below deck,* and similar terms may be used with respect to flying boats.

Because many terms used with respect to ships are applicable to flying-boat hulls and floats and quite frequently to fuselages, it may be best to handle them first. *Displacement* is the total volume of water displaced by the hull when the boat is afloat. The *keel* is the bottom plate. A straight line just inside the keel plate running fore and aft is known as the *base line.* *Water lines* are fore-and-aft lines parallel to the base line, usually equally

spaced; *water planes* would be a more accurate designation. *Molded breadth* and *molded depth* refer to dimensions measured just inside the hull plating. *Draft* and *trim* are synonymous with the terms used with reference to ships and boats. *Dead rise* refers to the amount that the bottom rises from the keel to the chine. *Tumble home* and *flare* refer to the sides of the hull leaning inboard or flaring outboard. The *chine* is the edge at which the side and the bottom meet. The *sponson* is a protuberance from the hull, increasing the beam of the hull. Floats and seaplane hulls have

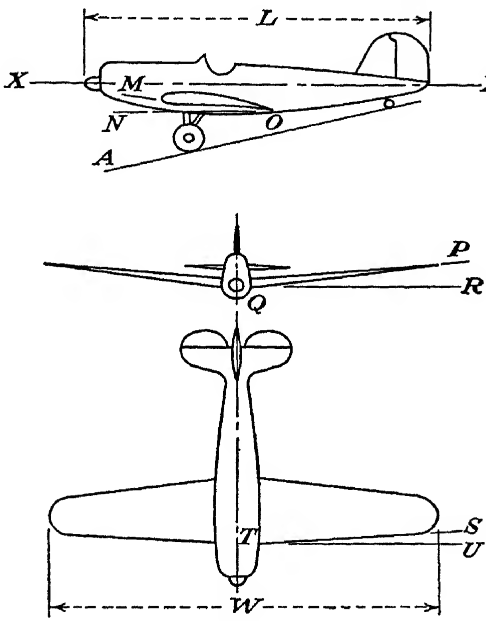

FIG. 1.

an abrupt change of section amidships, resulting in a *step* in the bottom. This step is useful in the take-off of the airplane.

The *stem* of a hull is the extreme bow on the keel line; the *stern*, the extreme afterportion. The *forefoot* is the stem near the keel.

In Chap. III, Lines and Fairing of Lines, other parts, particularly concerned with lines, will be described and defined.

The wing of an airplane has a complete nomenclature that is essentially applicable to itself, to the airplane of which it is a part, and to the airfoil from which it is derived. First, we shall list the wing parts. Wings are usually made up of a *center section* (part securing to the fuselage) and of outer panels. The *panel*

is a major part of the wing made up separately and secured to the center section near the wing root. The *wing root* is the point at which wing and fuselage meet. The *wing tip* is the outer extreme of the wing. The *aileron* hinges on the wing. The *wing flap* extends from the wing at its trailing edge. The *trailing edge* is the afteredge of the wing; the *leading edge,* the forward portion. The *slat* is an auxiliary airfoil in the leading edge which can open to make a slot and close to form a part of the wing leading edge. A *spoiler* is a small plate in the upper surface of the wing which is used to disturb the air flow. The *wing primary structure* consists of *spars* (or beams), *ribs, struts, brace wires,* and *covering.* Where we have a biplane to consider, we have external wing wires and struts to hold the wings in relative position.

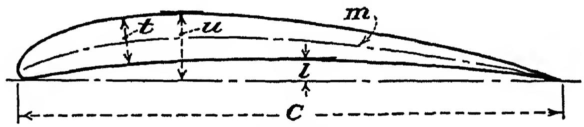

FIG. 2.

An *airfoil section* (see Fig. 2) is the cross section of a wing or surface. Essentially the profile is a shape. It has *chord length c, profile thickness t,* a *mean line m, upper camber u,* and *lower camber l.* Airfoil sections may be applied to wings and to tail surfaces.

To go on with wing nomenclature, which is likewise applicable to many parts of the tail surfaces, we come now to terms concerning shape and form. *Wing area* is the area projected by the wing on a plane of the chords. The *span* is the distance from wing tip to wing tip. The *chord length* is the fore-and-aft dimension. The *mean chord* is the average chord length. The *aspect ratio* is span divided by mean chord. The *wing axis* is the locus of the aerodynamic centers of all the wing sections. The *plan form* developed is the plan of an airfoil as drawn with chord lines at each section rotated into a plane parallel to the projection plane and with the wing axis rotated into the projection plane. A wing may taper in plan and in section from tip to root. The shape of the tip may be raked. A wing twisted about its axis is warped. This warp, giving increase in angle of attack toward the tip, is *washin.* Decrease in angle is *washout.*

Movable tail surfaces and ailerons may be aerodynamically balanced by having part of the area forward of the hinge point.

Elevators and rudders project into the stabilizer and the fin areas to produce this balance.

There remain some general airplane definitions worthy of note. *Streamline* is the path of a particle of a fluid relative to a solid body past which the fluid is moving, the flow being without eddying. *Turbulence* is eddying flow. The *slipstream* is the current of air driven by the propeller.

We come now to definitions of terms applicable to the aircraft mold loft. The *loft floor* is the area (specially prepared) where the lofting work is done. To a large extent, the aircraft industry has adopted a low platform for the loft floor. It is on this floor that the laying off of the airplane occurs.

Laying off is the work of drawing and fairing the full-scale lines of the airplane and the preparation of the templets of the airplane structural parts. The *templets* are the molds for a part, showing size, shape, form, and operations to be performed to make the part from raw material.

Fair lines are lines having continuity without abruptness. They give graceful form.

A *model* is a small-scale replica in that it is similar in shape to the full-scale object. A *mock-up* is a full-scale replica made up with skeletonized wood, the construction simulating conditions found in the airplane as far as space and form are concerned. An *assembly form* is for assembling parts and holding them in position before riveting or bolting.

Lifting a templet consists in taking dimensions from the floor for making the templet.

Expanding a part is the development of a shaped part into a flat plate area for the blanking-out operation. *Blanking out* refers to cutting the raw material preparatory to its being formed into a part.

Bevel is the angle given to a shaped bar to make it conform to the lines. Frame angles have various bevels, depending on their position.

Sight edges are plate edges as seen in the actual airplane fuselage or hull.

Contracting consists in bringing frames closer together than they actually are in practice, other dimensions being held to full scale.

Off-sets are dimensions of points on a curved line from a fixed straight reference plane.

Battens are light wood strips easily bent to follow a curve. They serve many useful functions in the loft, the principal ones being length measurement and establishing the lift of a curved line. A baseboard is a wood straightedge.

There are other terms and expressions peculiar to the loftsman which will be dealt with as they are met in the text.

Lofting in General. The airplane has two qualities fundamental to its existence: its ability to move fast and its ability to attain altitude. The first is of primary importance in transporting a useful load, commercial or military; the second is of importance in attaining a position of advantage, commercial or military. The airplane has the distinct advantage over other modes of transportation of being high-speed. This combined with the ability to attain altitude gives it an unparalleled range of usefulness.

It can readily be seen that an airplane requires above all things a construction whereby the drag, or resistance, of the vehicle is not abnormal. Reducing the drag of an airplane in the air without affecting other qualities improves its performance. Improving performance gives more than a higher efficiency in the sense that it results in a closer approach to an ideal. Although designers have much to do with the qualities of the airplane, they must depend extensively on the mechanics to fulfill their hopes. Of the mechanics charged with the manufacture of airplanes, the airplane loftsman is regarded as being vitally important.

An airplane would be most effective in carrying its useful load if it could be made as a shell. There is much that goes inside the airplane that governs its size. However, a structure that reduces to a shell cuts size and gives an improved vessel.

All that we intend to bring out here is that we are concerned with a streamlined structure which contains the essential mechanisms and a useful load and which must have a form convenient and efficient for performing its functions.

The engineers and draftsmen produce the design, the calculations, the drawings, and the specifications to which mechanics build the airplane. Loftsmen take the plans of the airplane, fair the lines in full scale, thus controlling the form of the airplane, and make templets, thus ensuring that parts will fit to produce the streamlined shape desired. In brief the draftsman is the artist and the loftsman, the sculptor.

It is clear that airplane lofting is a matter that requires the best skill available. An airplane cannot deviate much from the specifications without a reduction in its performing ability. At best the design and construction of an airplane require skilled handling. Of those concerned in the production of airplanes, there can be no doubt that the loftsman is paramount in influence. All that follows is directed toward improving the student's ability in those things with which the airplane loftsman is concerned. However, though one may get ideas and basic principles from these notations, the ability of a full-fledged loftsman can come only from experience on the mold loft floor.

Although the mold loft is charged with the making of templets, it has a major part, also, in model-making, mock-up, form assembly, pattern-making, and other aspects of airplane manufacture. Insofar as possible, we shall regard the airplane loftsman here in the broader light.

In laying off an airplane in the mold loft, a means must be found for changing designs made in two dimensions on a small scale on the drafting board into the completed airplane in three dimensions, full scale. The process for accomplishing this result is chosen with regard to convenience, accuracy, economy, and efficiency. As a matter of fact the processes used are adaptations of various kinds and become, in practice, intricate, difficult, and slightly inaccurate.

The simple approach is the basis of the method of analysis adopted here. It is quickly understood and readily applied when the student gives thoughtful attention to each step in its regular order. A studious analysis may give the reader ideas for improved practices.

The basic principles for the solution of loft problems are found in plane, solid, and descriptive geometry. The best rules and practice regarding laying out are the result of the experience gained in mold-loft work done in shipyards. The art has developed with shipbuilding, though aircraft builders are now initiating improvements that may modify to a material extent laying off both ships and airplanes.

In the mold loft, we are concerned with the airplane structure. The practices and procedures may be applied equally well to the construction of other parts of the airplane; however, generally speaking, the loftsman limits himself to the structure.

Laying off in the mold loft facilitates the manufacture of airplane structures from the sheets and shapes and similar raw materials. These raw materials are usually flat or straight or of some other regular shape. In order to use them in an airplane, we have to form them to some shape that may be far from regular. Many parts go to make up the whole; and, for the parts to fit together properly without much cutting and trying, we must know the best ways of forming and shaping metals to the desired plan.

Now, before entering into a detailed analysis, let us set up the problem again in relatively general terms, so that we shall not lose sight of its major aspects.

The draftsman has before him the work of designing an airplane structure so that it can be made by mechanics from the available raw materials. He has to make a plausible structure and one suited to the tools available in the shops and within the capabilities of the workmen. The draftsman sees in three dimensions and works his designs in two dimensions. True, he puts more than one view, if necessary, into his drawing; but it is only a flat sheet of paper that is his product. He may resort to perspectives, isometrics, and several other schemes to give a better picture, but the usual result is still a two-dimensional view.

Generally, the draftsman is forced to make a scale drawing. Actual size has so many disadvantages that scale, large or small, is common practice. For large objects such as airplane structures are likely to be, a small scale is convenient. Convenience and degree of accuracy govern the scale in most cases.

We come now to the gist of the reason for the loftsman. The draftsman's drawing is to a small scale. The workman building the article has to go to full scale. If the mechanic worked directly from the drawing, inaccuracies would be common. The loftsman overcomes this difficulty by scaling the drawing up to full scale. But he does something more—he makes a full-scale mold so that the mechanic can make the part directly to the mold without further trouble. Of course, there is more to the process than that; but, in general, this is a sufficiently accurate picture until we can analyze the details further.

Description of an Airplane. As it flies, the airplane is composed of those things which make up the useful load and those which make up the weight empty. The useful load comprises about 50

per cent of the all-up weight and consists of crew, fuel, and military load or pay load. The empty weight is composed of the airplane structure, the power plant, and the fixed equipment. Although the loftsman may meet the power plant and the fixed equipment of an airplane in making the mock-up, in laying out control lines, in arranging equipment, and incidentally in the airplane structure, his principal concern is with the basics of the airplane—the vessel and its form.

Although airplanes may be arranged in various ways and may deviate materially from the conventional types, we shall confine our discussion to typical landplanes and seaplanes. In a landplane, we have fuselage, wing, lateral control surfaces, tail surfaces, landing gear, power plant, controls, and equipment. In a seaplane, we may have a float-type landing gear to take the place of the wheel gear. Or we may have a flying boat in which a hull serves as the fuselage as well as the landing gear.

The fuselage is in the nature of the container as well as the body of the airplane, acting as the structure to hold the whole together and giving proper position to the various parts. It is built as a girder to give attachment for the wings and to support the power plant, the landing gear, and the tail surfaces.

The wings of an airplane are its working members. They produce the lift that supports the airplane in the air. The lift produced by the motion of the airplane through the air is carried to the fuselage by proper structure. Where the engine is in the wing, as in large multi-engine airplanes, or where equipment is installed in the wing, the fuselage structure is reduced accordingly. On the other hand, where wing power plants do exist, there are other forces such as thrust and resistance for which strength must be provided.

The control surfaces exist as part of the wings, for example, as ailerons, flaps, and spoilers, and as part of the tail surfaces. All parts of the tail group except the fin and stabilizer are movable. All these surfaces are built as thin streamlined areas intended to deflect the air movement and thus give maneuverable control to the airplane. The tail surfaces give aerodynamic balance to the airplane and permit a stabilized condition to exist. The fin and rudder give directional control, the stabilizer and elevator give longitudinal control, and the ailerons give lateral control. The control system is built to give various degrees of simulta-

neous action so that the airplane can make various degrees of curved flight from various attitudes. The wing flaps and spoilers are for improved take-off and landing operations and to control some special air maneuvers. A type of control used in some airplanes for reducing stalling speeds is known as a "leading-edge slot." Essentially the slot is a small auxiliary airfoil placed in the leading edge of a wing. It can be opened or closed, or it may be of the fixed type.

The wheel-type landing gear is a strut-wheel arrangement supporting the airplane as a whole when it is in contact with the ground. Wheel landing gears have oleo-struts to reduce the landing accelerations, which in turn reduces the structural strength that would otherwise be necessary. The tail wheel is a part of the landing gear, giving support when the greater part of the airplane rests on the ground. The tricycle landing gears (with a front wheel) give an improved attitude to the airplane when land-borne. Landing gears are fixed or folding in type. Fixed gears are ordinarily fitted with fairing to reduce resistance. Folding gears fold into fuselage, wings, or nacelles when the airplane is in flight, thus reducing drag. The folding mechanism is of a nature that concerns the loftsman, for it cuts into the airplane structure in a way to make the matter of construction a complicated one.

The engine cowling, the engine nacelles, the cabin structure, and many other parts of the airplane are important details with which the airplane loftsman must become acquainted. Before proceeding however, brief mention will be made of controls and equipment. Connecting the pilot's control with the movable surfaces, the folding mechanisms, the engine accessories, and similar items involves the consideration of two items—ratios and leads. The ratios come from the lever arms used. Layouts of these must be accurate. The directions of the leads constitute a complicated question, for all too frequently controls go through structures and interfere with equipment. Care in the mold loft may do much toward ensuring the essential clearances.

Equipment can be spotted correctly by use of a mock-up or by a judicious consideration of the full-scale lay-offs. If too much room exists, there may be waste space. However, because the weights of equipment are usually concentrated near the center of control, for one reason or another, the space allowed is often too

small. Only by study in full scale can the problem be solved correctly. It is clear that this field is an important one for the loftsman. Guns, seats, fuel tanks, instruments, electric wiring, radios, ventilators, and upholstery are only some of the many installations for which space must be provided.

The float-type landing gear usually found on a light seaplane is in the nature of an enclosed boat functioning to give buoyancy to the seaplane while it is water-borne. The float bottoms are designed to give small water resistance, and the float as a whole is shaped to give as little air drag as is consistent with its other functions. From the loftman's viewpoint, floats are very carefully arranged in form, requiring full appreciation of the "lines" of the object. Some landing gears are twin float types; others have a large main float and small wing-tip floats.

The flying boat, considering the larger sizes, comes close to being a true cross between ship and airplane. The hull of the flying boat has many of the features of the ship hull. One great difference, however, is that flying-boat hulls are designed for high speed on the water. In the larger types of flying boat the wings have some of the functions of the fuselage, the size being such as to allow conveniently for operating space, equipment, engines, etc. Multiple decks, double bottoms, collision bulkheads, ground tackle, and similar features common in ships of the sea have become very useful in flying boats. In working on flying-boat hulls the airplane loftsman can borrow freely from the ship loftsman's experience. As will become evident later the expressions and definitions used with reference to the ship hull are used also in connection with the airplane hull, to the distinct advantage of the airplane designer and mechanic.

Airplane Design. Airplane design is the result of a knowledge of physics, laboratory tests, experience, and deduction. To a greater extent than is now appreciated, airplane design is approaching a kind of standardization. To accomplish the desired results the airplane designer is forced to accept the best that his experience has shown him, with little opportunity to depart from that which is generally accepted unless he is interested in radical innovations. In undertaking the radical design, however, he runs the very great risk of failure. The general tendency in design is to hold to known facts and make detailed improvements wherever practicable.

The airplane design is based on the desired performance and certain operational features. Previous types expanded or contracted will give the estimated size and weight. From this the designer can calculate power required and wing area needed. These data permit the making of sketches sufficiently close in dimensions to show whether or not the design is feasible. Numerous studies, calculations, detailed sketches, and correlating adjustments enter into this phase of the design. In some cases, small models are used, as an aid in working out features that cannot be visualized in the normal two-dimensional drawings.

When the gross weight, the general arrangement, the power plant, the materials of construction, the over-all dimensions, and the other main features are decided on, it is possible to make some drawings and calculations as a basis for the next move. Most of this work can be labeled the *preliminary design stage.*

The size and type of the power plant control the cross-sectional shape of the fuselage if the airplane is to be single-engined. In the case of wing installation of engines, the design of the fuselage section is governed by the equipment and the useful load. The length of the fuselage is influenced by the necessary tail location.

The wing profile is selected from known test data regarding lift and drag. Wing area, and thence the span, are determined from the stalling speed. The tail surfaces are calculated from the wing area, as are the lateral control surfaces.

The wheel-landing-gear size depends on the propeller clearance, the float gear on the required buoyancy, and so on.

The sizes of the elements to be incorporated in the airplane have the greatest influence on the form. The weight of the airplane and the relative strength that must be built into the airplane govern the structure. The types of construction possible are numerous, but airplane manufacturers follow a general line of development. Aluminum-alloy semi-monocoque riveted fuselage and metal-covered wings are usual in most airplanes built to carry large loads.

The general arrangement having been determined, together with fairly good data on sizes and shapes of the main features, the designer turns to his types of construction. The "line" drawings of fuselage, wings, surfaces, etc., are developed while the construction features are studied. The line drawings are made to a small scale and are subject to much adjustment. A

quarter- or a half-scale line drawing reveals discrepancies in curves that need fairing and development. Line drawings will be discussed extensively in Chap. III, Lines and Fairing of Lines.

The designer then proceeds to work up the detailed design so that he will have assembly and parts drawings for the entire airplane, all dimensioned and regulated to suit other parts and to suit the lines that have been established. Calculations regarding the strength and the operational aspects of parts are made as the design proceeds. All parts are calculated for weight.

Depending on the experimental nature of the airplane, it is not unusual to build a mock-up of the whole. A mock-up serves to place equipment accurately, to indicate accessibility of items, and to give a good indication of spaces to be occupied by crew, passengers, and other factors having to do with the useful load. The mock-up has wings, engine, and tail surfaces arranged to give a good idea of the pilot's range of visibility.

The loftsman receives line drawings as well as construction drawings from which he develops his work. In some cases the construction drawings may be so advanced as to give detailed parts drawings together with assembly drawings. More frequently the loftsman must work from drawings that are combined assembly and detailed drawings.

The design is subject to a great deal of changing and modification in details as the construction proceeds, owing to later knowledge and improvements and in order to remove interferences. It is rightly said, "The design is never finished."

Airplane Construction. The manner of constructing an airplane depends upon whether or not the airplane is experimental in character or is ready for large-scale production. It depends also upon the plant equipment available for the work. Airplanes are built in varying quantities, principally because quantity production has not been warranted by the degree of standardization now existing in the industry.

The airplane design goes through a tooling stage as its first step. Two groups of parts are concerned: machined parts and sheet metal parts. Machined parts include everything from fittings to complete assemblies. A landing gear is an example of a machined assembly. The sheet metal parts include structure, fairing, equipment brackets, cowling, etc. Sheet metal tools consist of templets, patterns, forms, rolls, dies, sub-assembly

jigs, assembly jigs, and similar items for manufacturing the individual parts and assembling those parts.

The first stage is the affair of the mold loft in that it is there that full-scale lines are laid down and in that the loft furnishes the templets required to manufacture most of the tools referred to above. For instance, a form needed to produce a bulkhead requires templets for the parts and for the assembly of the parts, all constructed to match and to fit within the laid-down lines of the airplane.

The second stage in airplane construction is purely a manufacturing one. Individual parts are made from the raw materials. Forged fittings machined, rolled shapes, pressed sheet metal parts, sheet parts from drop hammers, hand-shaped sections, and machined rod are examples of the products of this stage.

The assembly of these parts by bolting, riveting, welding, threading, etc., into unit parts forms the third stage. Aside from the making of the parts, this third stage utilizes more jigs, fixtures, forms, and other templet products than any other major operation in aircraft construction. The output consists of wing ribs, surface ribs, beams, cowling, bulkheads, frames, tanks, fairings, control assemblies, struts, engine mounts, equipment mounts, instrument boards, shell plating, wing covering, etc.

In order that final assembly of an airplane may proceed rapidly and effectively, it is usual to have the major parts of an airplane brought as near completion as is practicable. Before describing the final assembly, therefore, the assembly of major parts may be mentioned as the fourth stage. Complete wing with much of the equipment and controls in place is one major part. The landing gear, either wheel or float type, is made into a unit with struts and wires in place. A minimum of time is consumed in setting it into place on the airplane. The power plant set in its mount with all accessories in place is another unit. Covered tail surfaces are prepared as a major assembly. And so with other large units. These major assemblies are checked with proper tramming and gauges to avoid any discrepancy in fit when they assemble to the fuselage and to each other. This measure is also a means for ensuring interchangeability.

Wiring, control leads, equipment, and piping can be installed in the major assemblies to good advantage when the quantity of

airplanes produced, of the type of the airplane under construction, has been great enough to give clearance and size information.

The final assembly operation is a time- and space-consuming matter in any case. There are many things to be tied together that cannot be handled conveniently otherwise. And after a particular group of units has been through the final assembly, the operation of the group requires delicate checking and adjustment to complete the matter. Connecting landing gear, wings, tail surfaces, and power plant to the fuselage is a final assembly operation. Equipment, instruments, armament, upholstery, etc., are installed. And after the airplane is a unit, each operating part is tested for correct functioning. Fixed parts are checked for proper alignment.

The airplane is given a test flight as the final check and inspection. It is ready for delivery.

This description of the construction has been skeletonized for the purpose of giving the student a brief outline only. More detailed discussions on this subject are available in books specializing on construction features.

PLATE II.—Typical metal templets.

CHAPTER II

GEOMETRY

General. Geometry is "that branch of mathematics which treats of space and its relations." As far as the loftsman is concerned, geometry is the basis for analyzing the problems presented and for reaching the answers to those problems. All lay-off work has its foundations in the treatment of objects in space. The simple way of treating objects is shown according to the various forms of geometry.

The loftsman takes his data from drawings of various kinds. The first requirement is that he must understand the drawing and visualize the object portrayed. Although the drawing is a two-dimensional portrayal, *i.e.*, it shows the object on a flat plane, it carries information regarding the length, breadth, and height of the object. It also shows variations in these dimensions so that it is possible to determine the shape of the object. Drawings are usually engineering drawings based on descriptive geometry. To use such data the loftsman must be able to interpret the draftsman's representation of the object drawn.

Using the drafting data, the loftsman produces a form of representation to full scale that is also in two dimensions, but that portrays a three-dimensional object. Because drafting data may be meager, the loftsman uses his full knowledge of geometry and trigonometry in laying off the work he has before him. Because the loftsman must be meticulously accurate, he uses his knowledge of mathematics in checking his results.

Having laid out the object on the loft floor to full scale, the loftsman lifts templets (see Plate II) which are forms for showing the shape of the object. The shop mechanic uses the templets to direct him in making the object to the correct size and shape. It is necessary for the loftsman to visualize the finished part in three dimensions when he makes a templet. In order to do that, he must have a knowledge of the properties of planes, angles, triangles, polygons, circles, curves, and all their combinations.

Plane geometry, solid geometry, descriptive geometry, and some trigonometry are the branches of mathematics of which the loftsman must have a knowledge. The study of analytical geometry, in plane and solid forms, is not essential, although the loftsman would do well to know of its existence so that he can call for engineering assistance along that line when he needs it to cope with a special case.

Mastery of the means of visualizing the airplane and its parts in three dimensions when these are portrayed in two dimensions is the foundation of all mold-loft work. The accurate transposing of data from drawings to the loft floor and thence to templets, forms, models, mock-up, etc., demands the use of the fundamentals of practical geometry. Sometimes model or mock-up portrayal is the only means available for exhibiting an intricate problem and its solution. Even in such cases, however, geometrical calculations will serve as records and as a method for conveying information.

Later on we shall discuss mathematical reproduction as applied to loft work and it will be shown that the loftsman can effectively use simple geometrical calculations as an alternative to extended layout and as a convenient means for checking a layout.

That which follows regarding geometry is at best a review. Any detailed proof or extension of the ideas given can be found in textbooks on the subject. To conserve time, essentials presented are limited to one aspect of the matter. Deviations, modifications, and combinations will come to the loftsman as he takes up practical work. Students will find it convenient to draw their own sketches to follow theoretical statements which are not illustrated.

Plane Geometry. Any book on plane geometry will give complete instructions for handling lines, areas, angles, and figures that occur in single planes. Because this is the basis for all layout work, the fundamentals of this subject are presented first.

Through two points, only one straight line can be drawn. Two straight lines cannot have more than one common point. A straight line can be of indefinite length. (A straightedge or a chalked line is used to produce a straight line.)

A circle is the line produced by a point which moves in a plane so that its distance from a fixed point is always the same. It has one center, and all radii are equal. A chord is a straight line

joining two points on a circle. A portion of the circle is an arc. (To draw a circle, use a pair of compasses or some equivalent means for holding a center and a fixed radius.)

An angle is formed by two straight lines (sides) meeting at a common point (vertex). Perpendicular lines occur when two lines meet to form equal adjacent angles, each of which is a right angle (90°). Angles are measured in degrees, each degree (°) being $\frac{1}{360}$ of the sum of all angles about a point. One-sixtieth degree is a minute ($'$), and $\frac{1}{60}'$ is a second ($''$). An acute angle is less than a right angle. An obtuse angle is greater than a right angle but less than a straight angle (180°).

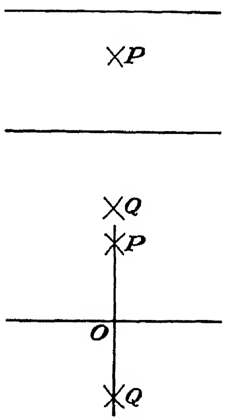

FIG. 3.

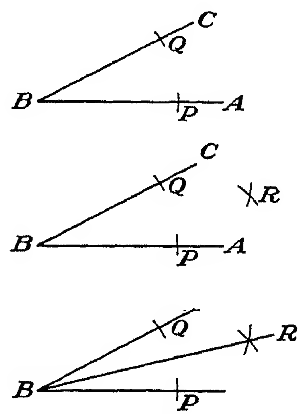

FIG. 4.

Complementary angles are two angles whose sum equals 90°. Supplementary angles are two angles whose sum equals 180°.

Join three points not in a straight line with straight lines, and you will have a triangle. A right triangle has one angle equal to 90°. An isosceles triangle has two sides equal. An equilateral triangle has three sides equal. A scalene triangle has no two sides equal.

To bisect a straight line AB (see Fig. 3): With A and B as centers and a convenient radius on the compass, strike arcs intersecting, as at P and Q. Draw PQ. Point O bisects AB.

Also, PQ is perpendicular to AB at O. Each angle POA, POB, etc., equals 90°.

To bisect an angle ABC (see Fig. 4): Using a compass with a convenient radius and B as a center, strike arc PQ. With P and

Q as centers, strike intersecting arcs at R. RB is the angle bisector.

To draw a perpendicular through a point P to line AB (see Fig. 5): With compass set at a convenient radius, strike arcs intersecting line AB at R and S. With R and S as centers, strike intersecting arcs at Q. Join PQ, which line is perpendicular to AB at O.

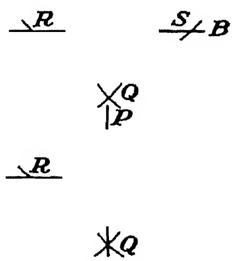

FIG. 5.

FIG. 6.

Parallel lines are straight lines that lie in the same plane and that do not meet even if extended. A transversal is a line intersecting parallel lines. Through a given point, only one line can be drawn parallel to another line.

Angles formed by transversal and parallel lines (see Fig. 6) have equality as follows:

$$a = c = e = g$$
$$b = d = h = f$$

To draw a line parallel to another line AB (see Fig. 7): Through C draw CD intersecting AB. At C, construct an angle equal to CDB, by using compass and arcs. Through C and the arc intersection, draw CE which is parallel to AB.

A polygon is a closed broken line in a plane. In a regular polygon, all sides are equal and all angles are equal. The sum of the interior angles of a polygon of n sides is $(n - 2)$ straight angles. In a regular polygon, each angle equals $[(n - 2)180°]/n$.

Similar polygons have corresponding angles equal and corresponding sides in proportion. Similar polygons can be divided into similar triangles.

Polygons include triangles, quadrilaterals, pentagons, hexagons, etc. Triangles are scalene, isosceles, equilateral, or right. Quadrilaterals are trapezoids, parallelograms, rectangles, rhombuses, or squares.

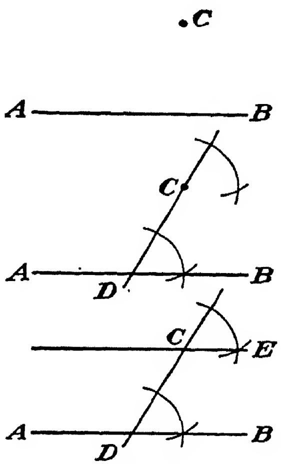

FIG. 7.

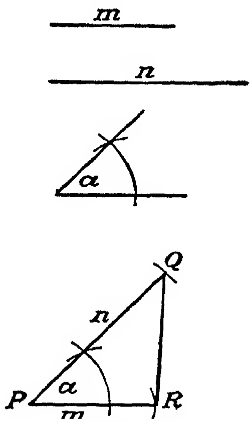

FIG. 8.

Any plane figures that can be made to coincide in all parts are congruent. Two triangles are congruent if respective

Side — angle — side are equal
Angle — side — angle are equal
Side — side — side are equal

Congruence of triangles is fundamental in proving congruence and equality between polygons other than triangles.

Constructing triangles can be done if the above-mentioned items of congruence are known. For instance, construct a triangle, knowing two sides m and n and the included angle a (see Fig. 8). Draw a straight line PR any length; with P as center and radius equal to m, strike arc at R. With P as center, duplicate angle a with arcs. With P as center and radius equal to n, strike arc at Q intersecting PQ. Draw QR. The triangle is PQR.

The sum of the angles of a triangle is equal to two right angles.

A line joining the mid-points of two sides of a triangle is parallel to the third side.

The perpendicular bisectors of the sides of a triangle meet in a point.

Bisectors of the angles of a triangle meet at a point two-thirds of the distance from any vertex to the opposite side.

A line drawn parallel to one side of a triangle cutting the other two sides divides these two sides proportionally.

The fourth proportion to three given lines a, b, and c is accomplished by triangulation (see Fig. 9). Draw AB and AC any length. On AB, lay off $AD = a$ and $DE = b$. On AC, lay off

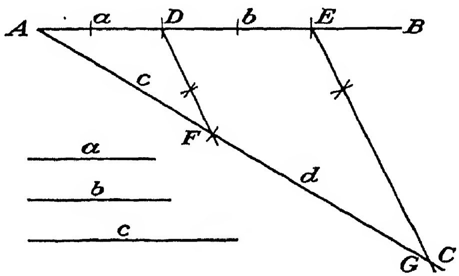

Fig. 9.

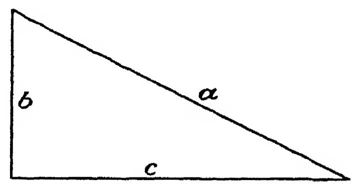

Fig. 10.

$AF = c$. Draw DF. Through E making angle $DEG = ADF$, construct EG parallel to DF. Then d is the fourth proportion sought.

If, in a right triangle, a perpendicular is drawn from the vertex of the right angle to the hypotenuse,

1. The triangles formed are similar to each other and to the given triangle.
2. Either leg is a mean proportional between the hypotenuse and the projection of this leg upon the hypotenuse.
3. The perpendicular is a mean proportion between the parts of the hypotenuse.

The square of the hypotenuse of a right triangle (see Fig. 10) equals the sum of the squares of the other two sides.

$$a^2 = b^2 + c^2$$

In an obtuse triangle (see Fig. 11),

$$a^2 = b^2 + c^2 + 2cx$$

In any triangle $b^2 = c^2 + a^2 - 2c(c + x)$.

The area of a

$$\text{Rectangle} = \text{base} \times \text{side}$$
$$\text{Parallelogram} = \text{base} \times \text{altitude}$$
$$\text{Triangle} = \tfrac{1}{2}\ \text{base} \times \text{altitude}$$

In a circle the angle between two radii is a central angle. Radii subtend arcs of circles. Concentric circles have the same center.

In the same circle, equal arcs have equal central angles, and equal arcs have equal chords.

Only one circle can be drawn through three points not lying on a straight line. To construct this, draw lines between the three points, and erect perpendicular bisectors. The intersection of the perpendiculars is the center, and the circle falls on the three points.

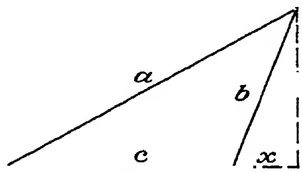

FIG. 11.

A secant is a line that cuts a circle at two points. A tangent is a line that touches a circle at only one point. Circles may be tangent to each other.

A line perpendicular to a radius at its extremity is tangent to the circle.

To inscribe a circle in a triangle, bisect the angles of the triangle. They intersect at the center. From that center, drop a perpendicular to a side which gives the radius.

To circumscribe a regular polygon, use the distance from the center to the vertex as the radius. To inscribe, use the distance from the center to the bisector of a side as the radius.

In a circle

$$\text{Radius} = R$$
$$\text{Length of circumference} = 2\pi R$$
$$\text{Area} = \pi R^2$$
$$\pi = 22/7, \text{ or } 3.1416$$

Solid Geometry. This branch treats of figures whose parts are not confined to a single plane. A plane is defined as a surface such that if any two points in it are taken the straight line passing through them lies completely in that surface.

Through one straight line, any number of planes may be passed. One and only one plane can be passed through three points not in

a straight line. Two planes intersect in a straight line AB (see Fig. 12).

Parallel lines or intersecting lines can determine a plane.

If a line is perpendicular to a plane, it is perpendicular to all lines in that plane and any lines in parallel planes. Any plane containing the line that is perpendicular to the given plane is perpendicular to the given plane.

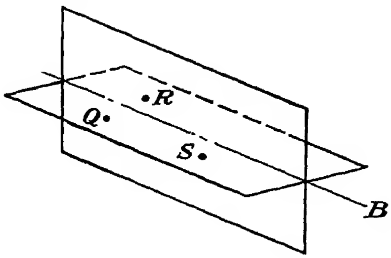

FIG. 12.

Two intersecting planes form the edge and the faces of a dihedral angle. The plane angle of a dihedral angle is its measure.

The figure formed by three or more planes intersecting in a vertex is a polyhedral angle. A three-face angle is trihedral.

A polyhedron is a limited amount of space completely surrounded by planes. Cubes, prisms, pyramids, etc., are polyhedrons. Regular polyhedrons, which have all faces congruent and edges equal, are limited to tetrahedrons (4-face), hexahedrons (6-face), octahedrons (8-face), dodecahedrons (12-face) and icosahedrons (20-face).

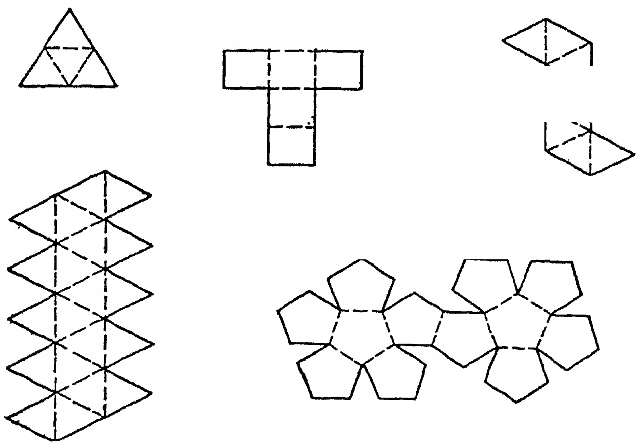

FIG. 13.

Cut out the shapes as in Fig. 13, fold on dotted lines, and you will have models of the possible regular polyhedrons.

The volume of a prism is equal to the base multiplied by its altitude. $V = B \times h$. Prisms may be regular, right, oblique, or truncated.

A pyramid is a polyhedron bounded by a polygon base and triangular lateral faces having a common vertex. The area of any face or base of a pyramid can be determined by considering the plane area. The volume of a pyramid is equal to the base multiplied by one-third the altitude. $V = (B \times h)/3$.

A cylindrical surface is a curved surface generated by a straight line moving parallel to itself and through a fixed curve. A cylinder is a solid bounded by a cylindrical surface and two parallel planes (bases). Circular cylinders have circles for bases.

A conical surface is a surface generated by a straight line moving with a point fixed in a vertex and following a fixed curve. A cone is a solid bounded by a conical surface and a base. The lateral area of a right circular cone is equal to the slant height multiplied by one-half the circumference of the base. $A = (l \times p)/2$. The volume of any cone equals the base multiplied by one-third the altitude. $V = Bh/3$.

If any solid of the kinds so far considered is bounded by two parallel planes B and T and if M is the area of another section parallel to and halfway between B and T, the volume V of the solid is given by

$$V = (B + T + 4M)\,\frac{h}{6}$$

This is the handy prismoid formula for estimating volumes of objects having the general shape of prisms, cones, cylinders, pyramids, etc. It is also applicable to spheres.

A sphere is a portion of space bounded by a surface, every point on which is equidistant from a center fixed point. A semicircle revolving about its diameter will generate a sphere.

A plane or a line having only one point in common with a sphere is tangent to the sphere at the point of tangency. The plane or line is perpendicular to the radius of the sphere at the point of tangency.

A section of a sphere made by a plane is a circle. If the plane passes through the center of the sphere, it is a great circle; otherwise, it is a small circle. Through three points on a sphere, only one circle may be drawn. Distance on a sphere is measured by the arc of the great circle concerned.

To determine the radius of a sphere (see Fig. 14): Use any point P as a pole. Draw the circle ABC. Take three points on the circle as A, B, and C, and make a plane triangle congruent to

ABC by measuring AB, AC, and CB with compasses. Circumscribe triangle $A'B'C'$, D' being the center, Draw $D''A''$ equal to $D'A'$. Through D'', draw $P''Q''$ perpendicular to $D''A''$. From A'', lay off $P''A''$ equal to AP. At A'', erect perpendicular

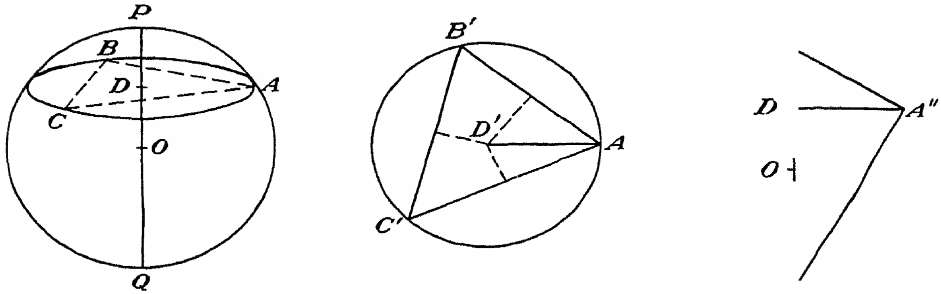

FIG. 14.

to $P''A''$, and extend until it cuts $P''Q''$. Bisect $P''Q''$ which gives OP'' equal to the radius sought.

To construct a sphere through four given points not in the same plane (see Fig. 15): Draw AB, BC, CD, etc., joining the points. At E, mid-point of AB, erect perpendicular plane QEP. At F, do the same with respect to BC, giving plane PFR. At G, mid-point of BD, erect perpendicular GQR. The intersection of these three planes at O gives the center of the sphere. OA is the radius.

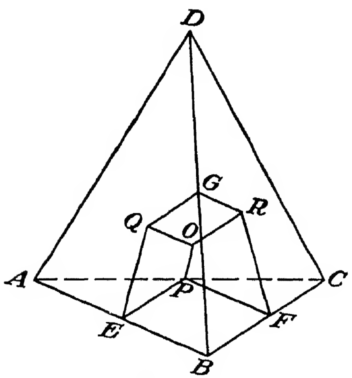

FIG. 15.

To inscribe and circumscribe spheres on polyhedrons, follow the rules laid down for plane geometry, remembering that inscribed spheres have tangent surfaces with polyhedron faces and circumscribed spheres go through the vertexes of the polyhedrons.

On the surfaces of spheres we may have spherical polygons of which the most common is the spherical triangle. The arcs of great circles form these polygons.

In Fig. 16 the spherical angle BPA between two great circles PAP' and PBP' is measured by the arc AB of a great circle described from the angle vertex P as a pole and included between

its sides. It is equal to the dihedral angle formed by the planes of the two great circles.

The sum of the angles of a spherical triangle is greater than 180° and less than 540°. Compare this statement with that which is applicable to the plane triangle. In a spherical triangle, we can have one, two, or three obtuse angles.

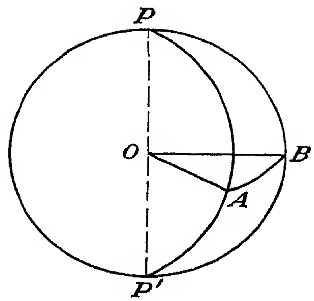

FIG. 16.

The sum of the sides of any convex spherical polygon is less than 360°.

The area of the surface (see Fig. 17) made by a straight line revolving about an axis in its plane is equal to the projection of the line on the axis multiplied by the length of the circle whose radius is a perpendicular bisector of the line terminated by the axis.

$$\text{Area} = CD \times 2\pi MN \qquad \text{(see Fig. 17)}$$

The area of the surface of a sphere is equal to diameter multiplied by circumference of its great circle. $S = 4\pi r^2 = \pi d^2$.

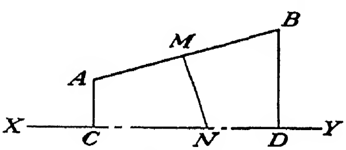

FIG. 17.

The volume of a sphere is equal to the surface area multiplied by one-third its radius.

$$V = \frac{4}{3}\pi r^3 = \frac{r}{3}(4\pi r^2)$$

Trigonometry. This is the branch of mathematics that treats of the methods used in subjecting angles and triangles to numerical computation. Trigonometry may be plane or spherical. The student will find here a discussion of only those parts of plane trigonometry that he will find useful in mold-loft work.

By the methods of plane geometry, if any three of the six parts of a plane triangle are known, other than the three angles, the triangle may be constructed and the unknowns determined by measurement. By trigonometry, we may calculate the unknowns.

Ordinarily angles are expressed in degrees, minutes, and seconds. Arcs of circles may be expressed as degrees of arc, each degree being $\frac{1}{360}$ of the circumference. For certain purposes, angles and arcs may be expressed in circular units. The

circular unit of arc is an arc of the same length as the radius; the circular unit of angle, called the *radian*, is the angle at the center subtended by this arc. A semicircumference is π times radius, subtending an angle at the center of π radians; thus, $\pi = 180°$. $\pi/2$ radians $= 90°$. 1 radian $= 57.3°$. $180° = 3.1416$ radians.

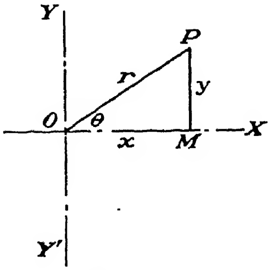

FIG. 18.

The angular space about the vertex of an angle may be divided into four quadrants of 90° each by a line coinciding with the initial side and one at right angles thereto. Angles are

In first quadrant when less than 90°
In second quadrant when between 90 and 180°
In third quadrant when between 180 and 270°
In fourth quadrant when between 270 and 360°

If from any point on one side of an angle a perpendicular is drawn to the other side, a right triangle is formed; *PO* is the hypotenuse, *PM* the perpendicular, and *OM* the base (see Fig. 18).

$$\sin\theta = \frac{\text{perpendicular}}{\text{hypotenuse}} = \sin\theta = \frac{y}{r}$$

$$\cos\theta \quad \frac{\text{base}}{\text{hypotenuse}} = \cos\theta = \frac{x}{r}$$

$$\tan\theta \quad \frac{\text{perpendicular}}{\text{base}} = \tan\theta = \frac{y}{x}$$

$$\operatorname{cosec}\theta = \frac{\text{hypotenuse}}{\text{perpendicular}} = \operatorname{cosec}\theta = \frac{r}{y}$$

$$\sec\theta \quad \frac{\text{hypotenuse}}{\text{base}} = \sec \quad \frac{r}{x}$$

$$\cot\theta = \frac{\text{base}}{\text{perpendicular}} = \cot\theta$$

In the various quadrants the signs are

Functions	Quadrant			
	I	II	III	IV
Sine and cosecant.	+	+	−	−
Cosine and secant.	+	−	−	+
Tangent and cotangent.	+	−	+	−

In any right triangle,

$$\overline{\text{side}}^2 + \overline{\text{perpendicular}}^2 = \overline{\text{hypotenuse}}^2$$

$$x^2 +$$

$$\frac{x}{r^2} + \frac{y^2}{r^2} = 1$$

$$\sin^2 \theta + \cos^2 \theta = 1 \qquad \tan \theta = \frac{\sin \theta}{\cos \theta}$$

$$1 + \tan^2 \theta = \sec^2 \theta$$
$$1 + \cot^2 \theta = \operatorname{cosec}^2 \theta$$

Every function can be expressed in terms of any of the above functions. Therefore, if we know one function, we can find the others.

Functions in quadrants in other than the first can be expressed in terms of the first. For instance,

$$\begin{aligned}
\text{(I) } \sin (90^\circ + \theta) &= \cos \theta \\
\text{(II) } \sin (180^\circ - \theta) &= \sin \theta \\
\text{(III) } \sin (180^\circ + \theta) &= -\sin \theta \\
\text{(III and IV) } \sin (270^\circ \pm \theta) &= -\cos \theta \\
\text{(IV) } \sin (360^\circ - \theta) &= -\sin \theta
\end{aligned}$$

The student can work out the other functions by studying his own diagrams.

Adding and subtracting angles gives

$$\sin (\theta \pm \theta') = \sin \theta \cos \theta' \pm \cos \theta \sin \theta'$$
$$\cos (\theta \pm \theta') = \cos \theta \cos \theta' \pm \sin \theta \sin \theta'$$

This is done by superposing angles diagrammatically.

Also,

$$\begin{aligned}
\sin 2\theta &= 2 \cos \theta \sin \theta \\
\cos 2\theta &= \cos^2 \theta - \sin^2 \theta = 2 \cos^2 \theta - 1 \\
2 \sin^2 \theta &= 1 - \cos 2\theta \\
2 \cos^2 \theta &= 1 + \cos 2\theta
\end{aligned}$$

which permits us to figure out any angle with which we are confronted.

Natural sines, cosines, and tangents are given in tables in engineering handbooks. For instance, the sine of 30° 26′ is 0.50654, and the cosine is 0.86222. In logarithmic tables we find

the log sine, log cosine, and log tangent. Logarithms are more convenient for solutions.

Solving a right triangle is done as follows (see Fig. 19):

$$a = c \sin A = c \cos B = b \tan A$$
$$b = c \sin B = c \cos A = a \tan B$$

Given:

$$A = 35^\circ\ 16', \qquad c = 672.3''$$

Therefore,

$$B = 90^\circ - A, \qquad a = 672.3 \times \sin 35^\circ\ 16' = 388.2''$$
$$b = 672.3 \times \cos 35^\circ\ 16' = 548.9''$$

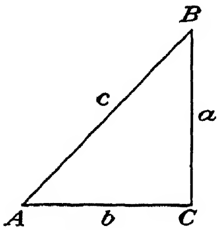

FIG. 19.

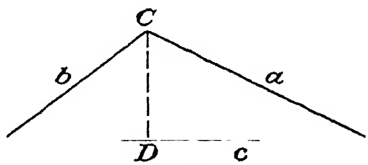

FIG. 20.

To solve oblique triangles, we can consider ABC (Fig. 20) as such. CD is drawn perpendicular to c, forming two right triangles.

Therefore,

$$\frac{\quad}{\sin A} = \frac{\quad}{\sin B} = \frac{\quad}{\sin C}$$

and

$$a^2 = b^2 + c^2 - 2bc \cos A$$

and

$$\frac{a - b}{a + b} = \frac{\tan \frac{1}{2}(A - B)}{\tan \frac{1}{2}(A + B)}$$

The area of an oblique triangle is equal to $\frac{1}{2}bc \sin A$.

These formulas will permit us to solve any oblique-triangle parts if three items (other than three angles) are given.

The radius of a circle circumscribing a triangle can be found by

$$\text{Radius} = \frac{abc}{4 \times \text{area of triangle}}$$

The radius of a circle inscribed in the triangle is given by

$$\text{Radius} = \frac{2 \times \text{area triangle}}{a + b + c}$$

Descriptive Geometry. Because solids have length, breadth, and thickness and drawing paper has but two dimensions, three to six orthographic views may be necessary to show an object correctly. In addition, sectional views may be required to complete the description. Mechanical drawing endeavors to represent the shape of a solid object so that the mechanic can make the object. If the object could be placed within a transparent cube and its silhouette projected onto the faces of the cube, we should have plan, front elevation, side elevation, and other views of the object. Mathematical rules and laws govern the projections. Now, if those faces with their silhouettes were laid out on paper, we should have a mechanical drawing as determined through descriptive geometry. Of course, there are abbreviations and special schemes for representation used in industry but the principles involved are essentially these stated.

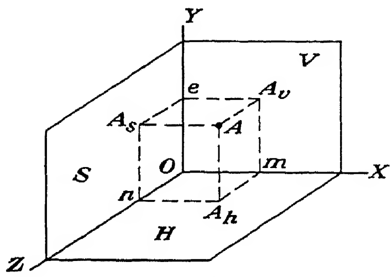

FIG. 21.

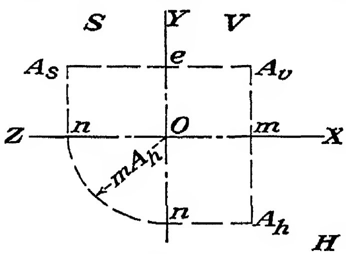

FIG. 22.

The method of representing a point in space by its projections and fixing its position relative to the reference planes is as follows. The reference planes are three in number at right angles to each other. In Fig. 21, XOY is a vertical plane, XOZ a horizontal plane, and YOZ a side plane. These planes are perpendicular to each other. A is a point in space. A perpendicular from A to the plane XOY gives A_v. A perpendicular from A to the plane XOZ gives A_h. A perpendicular from A to the plane YOZ gives A_s.

We can assume XOZ and YOZ as having swung into the plane of XOY. The point in space can be located by three views, the distances from axes being projected lengths.

In Fig. 22, A_v, A_h, and A_s represent the point A relative to the axes definitely located on a drawing. The point A is represented by projections, and the projectors are represented by coordinate distances each coming into the drawing three times.

The laws governing this projection of a point are as follows:

A_v must be vertically above A_h.

A_s must be in the same horizontal line as A_v.

A_s must be to left of YO by the same distance as A_h is below OX. So, if two projections of a point are known, the third can be found.

Projecting a series of points in a straight line will give a straight line on the reference planes. In Fig. 23, to find the horizontal H, vertical V, and side S projections of a straight line, project the extremities on each reference plane and connect the projections of the extremities. A is projected onto the three views as shown. Then B is projected onto the three views. A_vB_v, A_hB_h, and A_sB_s are the projected lines.

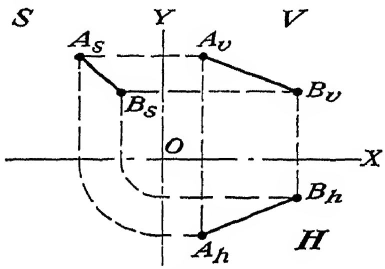

Fig. 23.

To find where the straight line will meet the reference planes if extended, we resort to similar triangles (see Fig. 24). A_hB_h extended cuts the horizontal plane at C_h. C_v is the vertical projection of C_h. Knowing the coordinates of A and B, we can find the coordinates of C by similar triangles.

A line parallel to two reference planes and thus to an axis will project to a point in one view and to its true length in the other two views.

A line parallel to one reference plane only will be projected to its true length in that view and foreshortened in the other two views.

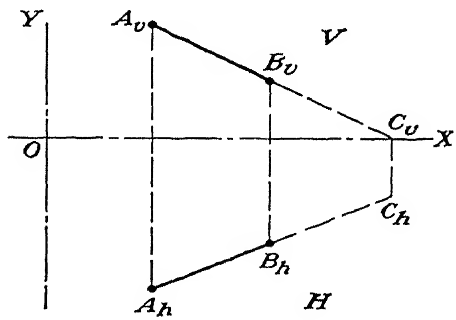

Fig. 24.

A point on the given line will project into all views of that line at a proportional distance from the end in each case. But a point in a projected view may or may not be on the given line. The student can easily prove this by making his own diagrams.

In finding the true length of a line AB given by its projections, the use of an auxiliary plane of projection is helpful. This auxiliary plane is made parallel to the given line and is made to

revolve into coincidence with one of the regular planes of reference.

In tbe case shown (Fig. 25) the plane U is parallel to the line because it is parallel to the horizontal projection. This plane U

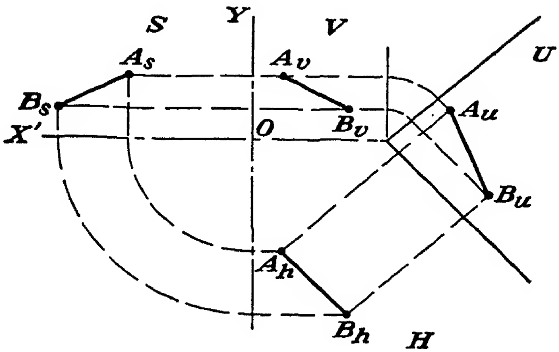

FIG. 25.

has been revolved about the axis, where it intersects with H, so as to bring it into the plane of the paper. Regard views V, H, and U as working together, and we have three views of the line AB projected. The space between V and U is construction space, as is the space between H and S. A projected gives A_u, and B projected gives B_u. The view U being parallel to the given line AB, the projection thereon is the true length of the line.

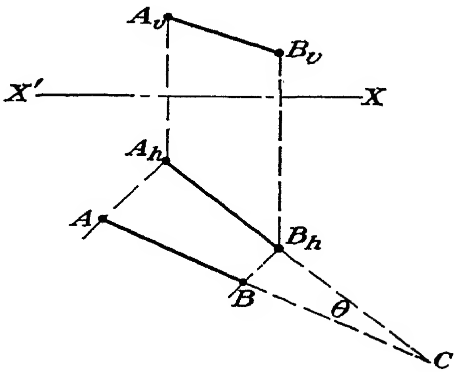

FIG. 26.

The abbreviated method for finding the true length of a line AB, the projections being given, uses the same principles. The process used (see Fig. 26) is to turn the line AB onto the H view about A_hB_h. From A_h and B_h, lay off perpendiculars to A_hB_h. Make A_hA equal to the height of A_v above XX' and B_hB equal to the height of B_v above XX'. Join AB, and you have the true length of the given line. Extend A_hB_h and AB until they intersect, making angle θ. This is the angle that the given line makes with the horizontal plane. By applying the

same procedure to the vertical view, we arrive at the same results with respect to the vertical plane.

Right triangles can also be used to determine the true lengths of lines from projected views. The student can develop his own example and solution from what has gone before.

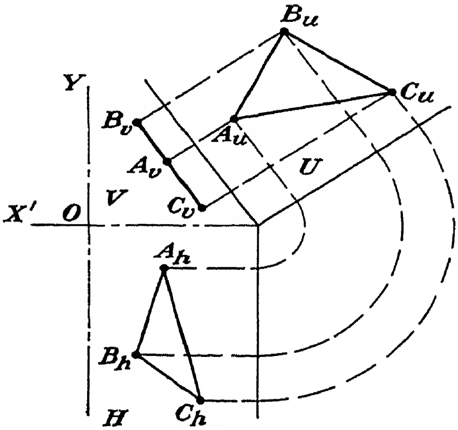

FIG. 27.

The use of an auxiliary plane is most helpful when the plane gives true length to a number of lines at once. In the case shown (Fig. 27), triangle ABC is shown in the V and H views. To develop the true shape, we use auxiliary plane U parallel to the vertical projection. Construction lines are shown to make $A_uB_uC_u$ the true triangle with edges and angles complete.

The student will notice that much matter can be left out of the projections without reducing their value. As we proceed, representations and lettering will be simplified to show that which is essential only. If at any time confusion exists in the student's mind, he can draw the figure represented on a separate sheet of paper for a model. Now, by folding along the axes and folding construction areas out, the problem can be seen in three dimensions. This is a ready means to improve visualization.

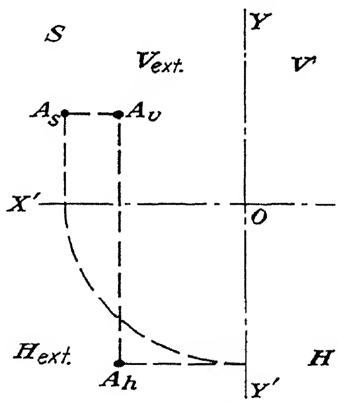

FIG. 28.

Before proceeding with surfaces, mention will be made of negative coordinates and traces. If the point A (Fig. 28) moves out of the transparent cube previously used, a negative coordinate will occur. To handle this condition, we extend the horizontal and vertical views to suit. A_v is in V extended, and A_h is in H extended. S, V, and H are as before. The construction lines show how the point is located. The X coordinate is negative. No

matter which coordinate is negative, it is handled in the same manner.

The "trace" of a line on a reference plane is the point at which that line pierces the plane if that given line is extended. A line parallel to an axis and perpendicular to another axis will give traces of a point and of a line. An inclined line will give traces of two points. An oblique line will pierce all three reference planes, giving point traces, one trace being negative.

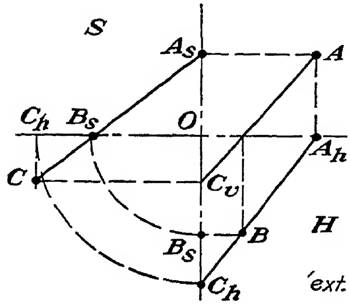

FIG. 29.

In Fig. 29, A, B, and C are the traces of the line AB extended to cut the three reference planes. It cuts the S view extended. The projections in the vertical and side views require extensions as shown. By constructing a paper box to represent this case the student will readily see the line and its traces.

Many structures with which the loftsman comes into contact are pieces all of whose surfaces are portions of planes, each plane

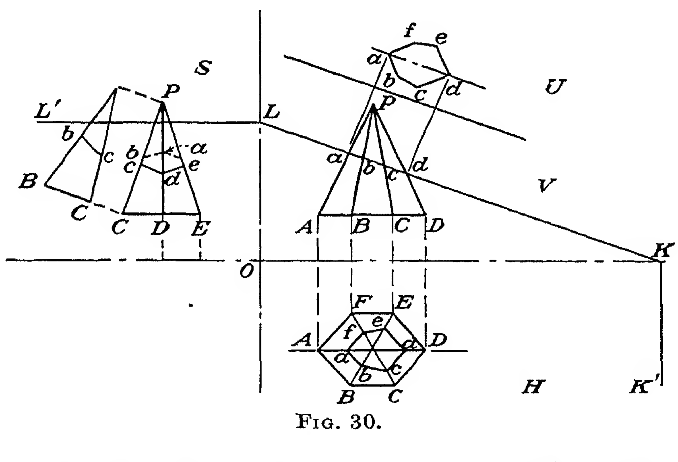

FIG. 30.

having a polygon face. Intersections in such cases are the important factor. Before discussing the usual loft problems a brief description of the mechanical drawing of intersecting surfaces will be given. In Fig. 30, we have a pyramid cut by an inclined plane. The traces of the plane are LK, KK', and LL'. The problem is to find the shape of the plane intersection in the

horizontal and side views and to find the true shape. Take PA in vertical view. This line intersects the cutting plane at a. Project a to planes S and H. Do this for b, c, d, e, and f. U is an auxiliary plane parallel to LK. If the usual practice in projecting is followed, *abcdef* in view U gives the true shape of the intersection.

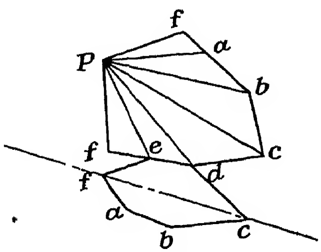

Fig. 31.

The development of the faces of a solid object is an important element in the loftsman's work. It appears most frequently in the preparation of templets for sheet metal work. The development can be effected if true lengths and shapes are available. The development of the pyramid above the intersecting plane is a simple problem which will give an idea of the principles involved. If we use the view U to give the base (see Fig. 31), triangles can be constructed, the lengths of the three sides being obtained in each case from the views shown. The triangles laid together form the development of the pyramid.

Planes of unlimited extent intersect reference planes in lines called *traces*. These planes may be parallel, inclined, or oblique. Traces of oblique planes may be all positive, or they may include a negative trace. If the plane considered is parallel to a reference plane, it will not intersect that reference plane but it will intersect the other reference planes.

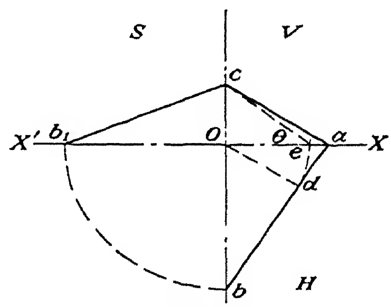

Fig. 32.

Figure 32 shows the traces *ac*, *ab*, and *cb* of an oblique plane. To find the angle this surface makes with the horizontal reference plane: From c, which may be any point in *ac*, drop a perpendicular to XX', as *co*. From o, drop a perpendicular to *ab*, *viz.*, *od*. $oe = od$. *ce* makes angle θ which is the required angle. If *co* is regarded as an axis and *ceo* swung thereon, *ce* will fall on the intersecting plane.

If a line lies on a given plane, the trace of that line on any reference plane will lie on the trace of the given plane on the reference plane. From this, we can pass a plane through three points,

and we can pass a plane containing the given line. Considering the latter case, we locate A and B (Fig. 33) by conventional procedure, A and B being the traces of the line EF. EF projections are as shown in the figure. Extend EF to B and to A as shown. Because the possible planes containing EF are unlimited, we must choose a limitation. If a is a point through which the plane must also pass, draw Aa and Ba. AaB is the required plane cóntaining EF and point a. If the plane were to contain EF and be perpendicular to view H (not including point a), BA_v and A_vA would be the traces of the plane. To be perpendicular to V, the traces must be BB_h and B_hA.

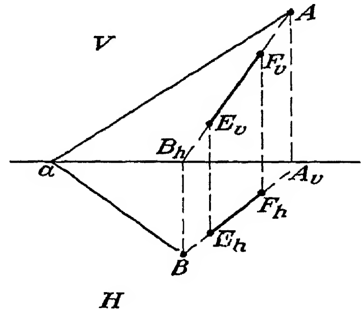

FIG. 33.

If a plane contains two given lines, the traces of the plane must contain the traces of the given lines. This solution can be applied only where the given lines are parallel or intersect. Two lines AB and AC (intersecting) are projected as shown in Fig. 34. Extending AB and AC to form traces F, D, G, and E, we can join E and G and F and D, forming the plane DOG which is the desired plane.

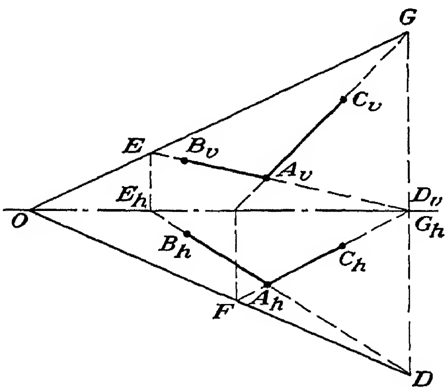

FIG. 34.

If two given planes intersect, they will produce a line at the points of intersection. This line being in both planes, it will pass through the reference planes where the horizontal plane traces meet and where the vertical traces meet. Thus, in Fig. 35, two planes AOB and APB are represented by their traces. Intersections at A and B give the necessary projection points so that AB_h and BA_v become the projections of the intersecting line AB.

The problem of making a plane perpendicular to a given line requires only the drawing of the traces of the plane perpendicular

to the corresponding projections of the line. In Fig. 36, PQ is perpendicular to A_vB_v, and QR is perpendicular to A_hB_h. PQ and QR are traces of the plane sought. To find the perpendicular distance of the point A from the plane POR (see Fig. 37), intro-

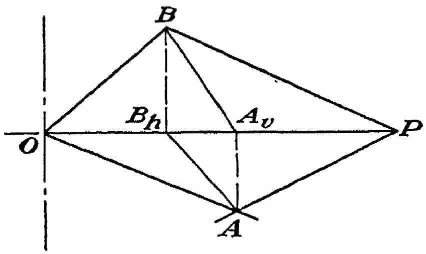

FIG. 35.

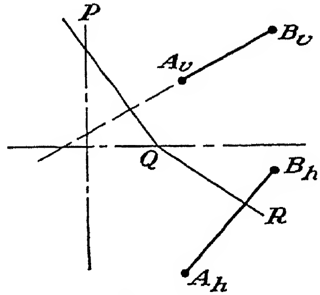

FIG. 36.

duce vertical plane MNL to contain line AB. ED_v and D_vD_h are the projection of the intersecting planes. The intersection of AB with line ED is on the line AB and in the plane POR. This is satisfied by point K_v, K_h. Finding the true length of K_hA_h gives the distance.

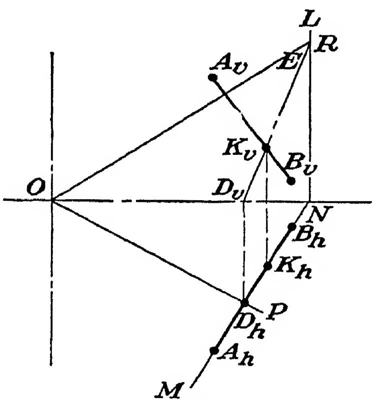

FIG. 37.

The angle between two oblique lines can be determined by the application of the previous elementary procedures. Used in combination, plane EQM (Fig. 38) is constructed containing AB and AC, the two oblique lines. The projections of the lines are shown. An auxiliary plane perpendicular to MQ, such as U, will show the lines AB and AC and the plane EQM on edge. A, B, and C will appear as A_u, B_u, C_u. Now, by revolving a part of the plane about A_u until it comes parallel to OM, we have A_uB_m. In the H view, C_h moves to C and B_h to B. CA_hB will be a true shape, giving the angle between AB and AC.

To find the angle between two planes as exhibited in Fig. 39: NOM and NPM are the two planes. The intersection line projected is NN_h and MM_v. A plane perpendicular to this line MN

will intersect the two planes NOM and NPM with lines that will give the angle sought. DE is the horizontal trace and ST is the vertical trace of this plane perpendicular to MN. Locate F;

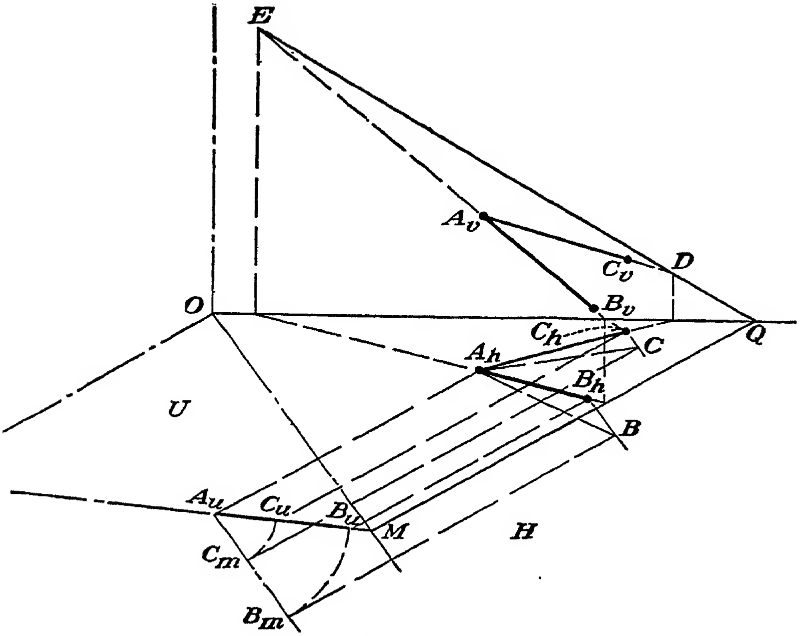

FIG. 38.

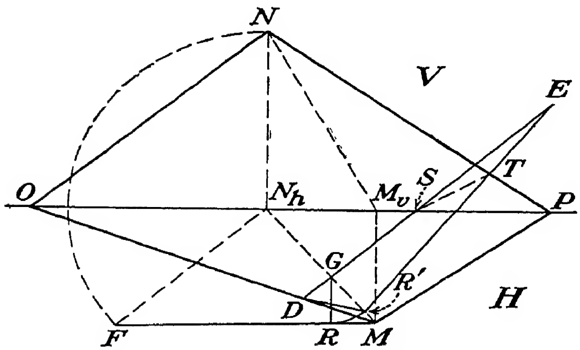

FIG. 39.

$NN_h = N_hF$ and N_hF is perpendicular to N_hM. MF is true length of the intersecting line MN. Draw GR (true length G to line MN) perpendicular to FM. Now, if the plane having lines GD and GE

is turned about DE as an axis until the plane is in H, R will move to R' and $DR'E$ will be the angle that can be measured directly.

So far in our discussion, we have limited ourselves to straight-line figures. We now come to the consideration of curved lines and the figures produced with curves. The simplest curve to handle is the circle. If the circle is parallel to a reference plane, it projects as a circle and a line, the line being a diameter in length. If the circle is in an inclined plane, we have projections appearing as lines, ellipses, or a circle. In one reference plane V (Fig. 40) the circle is a straight line; in the auxiliary plane U, we see the circle; in each of the other two planes, H and S, the circle appears as an ellipse.

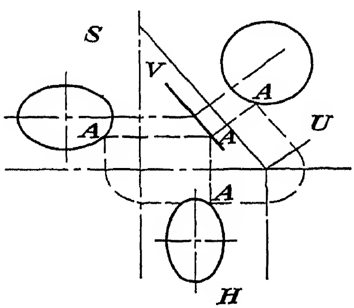

FIG. 40.

If the circle is in an oblique plane, it appears as an ellipse in each of the three projections. Occasions may arise where regular curves (not closed) are to be projected. A simple example (Fig. 41) will suffice. A helix similar to a screw thread is shown. In one view the helix appears as a circle. Divide the circumference of this circle equally. In the other view, we have "pitch" given. Divide the pitch into the same number of parts. The construction from this point on is evident.

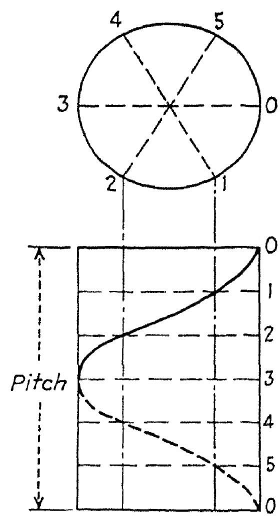

FIG. 41.

To describe an irregular curve in space, we can handle it by knowing coordinates of points on the curve (Fig. 42). After some points have determined the curve, we can follow the projections through by the usual rules regarding projection of points in space. When we have enough points, we can draw smooth curves to represent the projections. By correcting and fairing the curves, it is possible to produce a nice projection giving three views, the projection curves being fair and smooth. To be correct, we must know the coordinates in all three reference planes. Knowing coordinates

in two planes, we can construct the curve in the third. Because enough points in a curve are not ordinarily available, the loftsman produces projections by a trial-and-error method, "fairing" being the important factor. If the curves do not fall smooth in all three views, corrections are applied in one view and carried to the others until all are coordinated and faired curves.

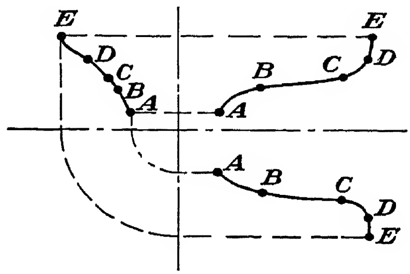

FIG. 42.

To represent solids having curved surfaces, it is necessary to take into consideration that the curved surfaces may not appear in all views. A right cylinder appears in one view as a circle and in the other views as a rectangle. Where the straight lines occur to show the curved sides of the cylinder, each point projected is tangent to the curved surface. This principle of projecting tangents makes it possible to project the curved surfaces.

If we revolve a line about an axis, we produce a "surface of revolution." Spheres, cylinders, cones, and similar forms are

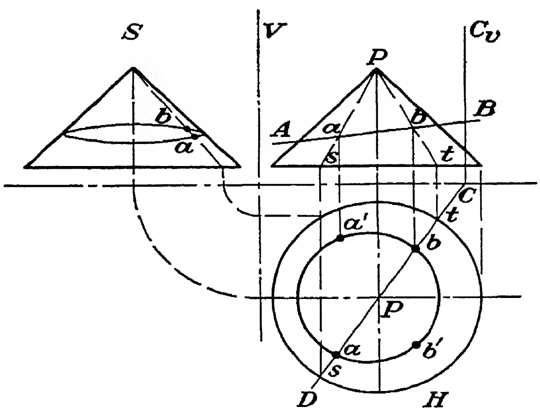

FIG. 43.

within a surface of revolution. Any object having circular cross sections throughout its length has a surface of revolution.

In order to handle the projection of curved surfaces intersecting curved surfaces, we rely upon auxiliary planes. These auxiliary planes cut elementary intersections of the given surfaces. The points of the line of intersection are used to project the inter-

section. Smooth curves passed through these points give the desired information as to the form.

Let us consider a right circular cone intersected by an inclined plane. In Fig. 43 the cone is intersected by the plane AB. An

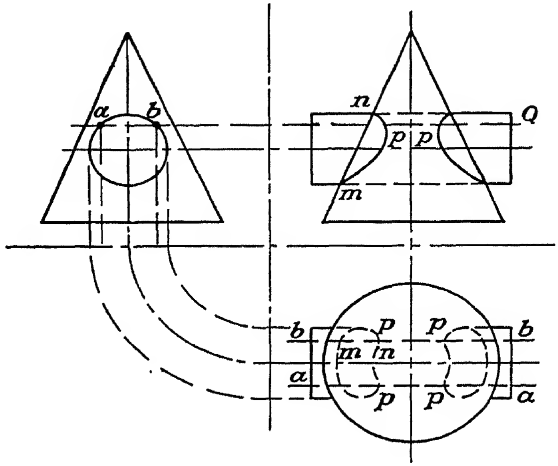

FIG. 44.

auxiliary intersecting plane CD through the axis of the cone has traces CD and CC_v. It intersects the cone surface in Pt and Ps. Project these (Pt and Ps) into the V view. The V projection of the intersection of CD with the plane AB is the line AB. a and b are points, intersections of intersections. Projecting these onto

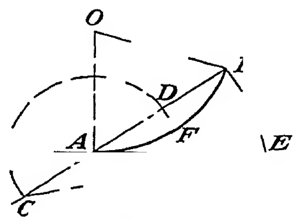

FIG. 45.

the H view and doing the same with other points, we can establish $ab'ba'$. Projecting these points onto the S view completes the information.

Consider the intersection of a cone and a cylinder (Fig. 44). Use Q as the auxiliary intersecting plane, which makes points a and b discernible. These give p points in the H and V views. If more planes parallel to Q are taken, we shall have all points neces-

sary to show the intersection of cone and cylinder. Additional planes have been omitted in the figure to avoid confusion.

The loftsman is continually confronted with the problem of the development of surfaces. If the curved surface to be developed has single curvature, the problem may be simplified. Single curvature implies straight-line elements perpendicular to the line of greatest curvature. If the curved surface is part of the circumference of a circle, it can be rolled out.

To rectify a short arc (see Fig. 45): Draw AE tangent to the arc at one end. Draw the chord of the arc AB. Bisect AB at D. Lay off $AC = AD$. Lay off $CE = CB$. Straight line AE equals the arc AFB.

Development of a right circular cone (see Fig. 46) will serve as another example. The surface of a cone takes the form of a sector

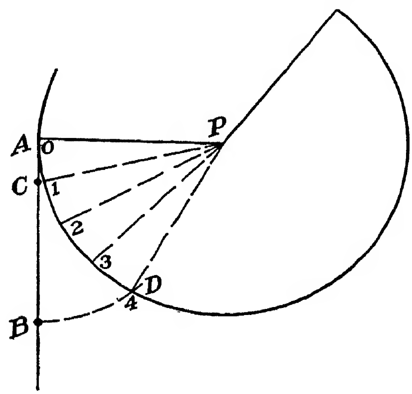

Fig. 46.

of a circle, the slant height of the cone being the radius and the arc of the sector being the circumference of the base of the cone. Rectify the circumference of the base. Let us assume that this has been done and that AB represents one-quarter of the circumference. Lay off $AC = \frac{1}{4}AB$. With CB as radius, strike D. Then, arc $AD = AB$.

By using the projection of the cone in the H, S, and V views and the development, properly divided into equal sectors as shown, we can handle such matters as intersections of cylinders with cone or of plane with cone, etc. The student can develop his own problems to full scale as good practical exercises in the development problem.

CHAPTER III

LINES AND FAIRING OF LINES

General. The airplane is shaped to give it the contour essential to its intended performance in the air. So much of the airplane's performance depends on the form of its parts that theoretical considerations must be carried into practice with care.

The first factor in respect to airplane shape is *drag*. To a degree, minimum drag results in efficiency. *Streamlining* is a term intended to signify low resistance. Essentially, this is a low-drag form that has been determined from wind-tunnel experiments. The principal point in this connection for the loftsman is that he must see that the form follows the design as shown by the designer and that shapes are fair.

The second factor with respect to airplane shape is *lift*. A large part of the lift of a wing is derived from its contour. In other words, a minor deviation in wing profile can destroy its lifting quality at certain speeds. Also, the effect of tail surfaces depends on the form selected for them. These shapes and forms have been evolved after extensive tunnel tests and much experience. The loftsman must regard these matters much as they are regarded by the designing engineer.

The high speeds at which aircraft are piloted make horsepower a very costly matter. Reduction in drag through true form is now so valuable in reducing the horsepower required that designers have gone to extreme measures in their search for innovations that will cut down drag. Where fairing of lines has eliminated protuberances and excrescences with resulting reductions in cross-sectional areas, these extreme measures have been warranted.

The flow of air about an airplane is a very complicated matter. The combinations of forms in use are not without their idiosyncrasies and inconsistencies. The airplane loftsman must regard his problem as refined by aerodynamical qualities. Deviations from design require consultation with the aeronautical

engineer whose knowledge of wind-tunnel experiments throws light on the results to be expected.

Aside from the contour of the parts, the airplane depends very much upon the relative position of parts with respect to each other. For instance, the angle of the wing with respect to the center line of the fuselage is a setting requiring precision for good results. The angle of the stabilizer with respect to the fuselage and the wing governs a moment which will cause the airplane to fly properly.

The airplane loftsman has greater responsibilities than the ship loftsman. The ship loftsman quite properly limits himself to the hull of a ship. The airplane loftsman often is working with seaplanes, which operate on water as well as in the air. Hence in such cases, all the hull difficulties are added to those of the airplane itself. Higher speeds and different mediums require a special technique.

Another matter of special significance to the airplane loftsman has to do with controls and their operation. Surface controls, for example, go through fuselage, wings, and other parts of the airplane, with due regard for equipment, structure, and other interferences. Were these controls not laid out to full-scale in the loft, much difficulty would be experienced in getting necessary clearances. And because they are movable controls, allowances must be made for the anticipated displacements.

The loftsman's accuracy combined with the skill of the mechanic in producing the parts will result in fine lines and excellence in the product. A high degree of accuracy in loft work is essential. Measurements can be made to closer tolerances than erection instructions permit. Lines and curves prepared carefully give exceptional results. But if errors creep into the lines and their measurements, they assume large proportions easily and show up as gross in the final product. The loftsman's technique must include precision.

There are three sets of lines that will serve as illustrations of the line drawings for an airplane. Hull and float lines are generally similar. The fuselage lines take on many of the characteristics of the hull lines. Wing lines, including lines for the nacelle, are specially arranged for wings, similar sets of lines being used for other surfaces.

Two procedures are widely used in the laying down of lines. The first is the more common. It consists in having the designers

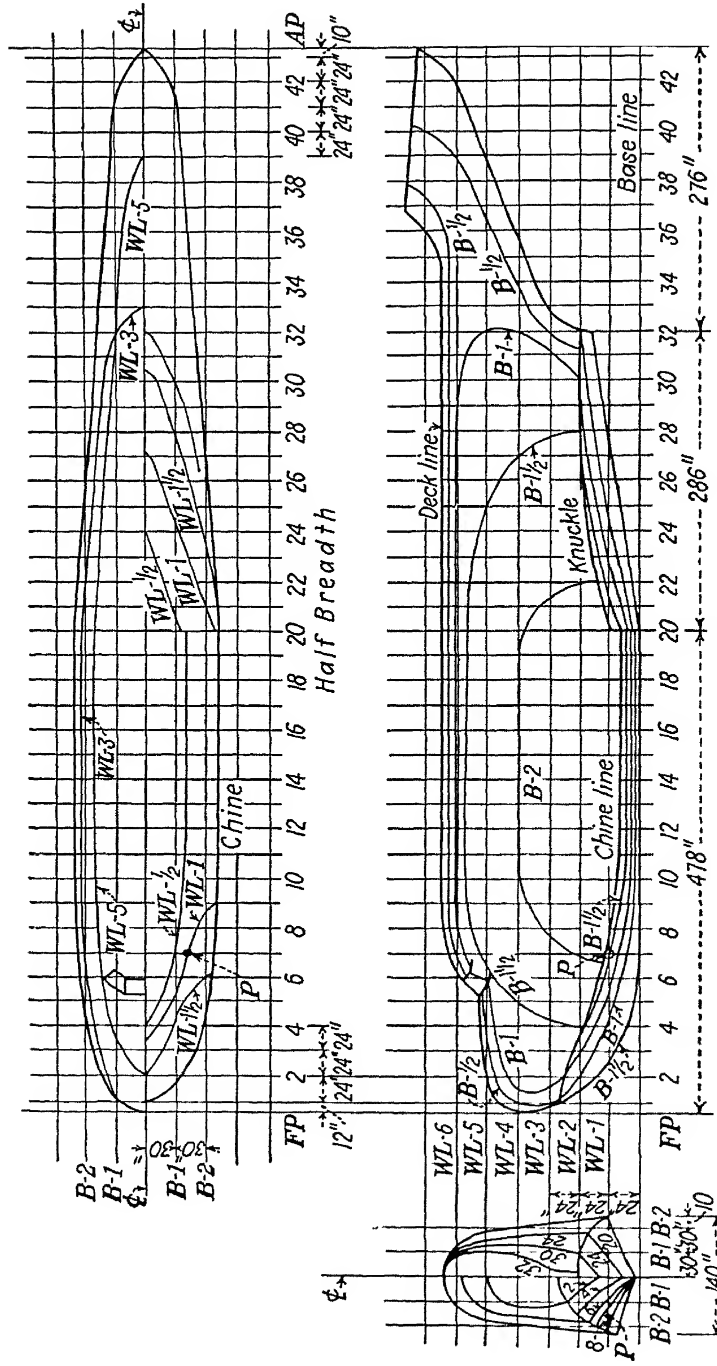

PLATE III.—Hull lines.

MOLDED OFF-SETS

Heights								Half Breadths							
Sta.	Keel	Chine	Deck	B-½	B-1	B-1½	B-2	Sta.	WL-½	WL-1	WL-1½	WL-3	WL-4	WL-5	Chine
F.P.	88	....	96-2	....	....	....	....	F.P.							
4	12-7	48-2	126-7	120-2	115-2	48-10	....	4	2-2	14-3	28-4	51-4	.....	34-2	58-10
8	1	24-3	154	150-1	144-4	132-2	75-7	8	32-1	46-10	.....	63-7	.....	48-6	69-3
12	....	17-1	160	152	145	135-7	95-4	12	39-6	.....	.....	63-7	.....	51-3	71-4
16	....	15-15	160	152	145	135-7	96-1	16	39-6	.....	.....	63-7	.....	51-3	71-4
20	4-3	16-2	160	152	145	135-2	91-2	20	39-6	66-2	.....	63-7	.....	51-3	71-4
24	15-8	38	160	152	145	122-10	....	24	2-1	34-6	58-2	57-10	.....	44-7	62-9
28	25	49-2	160	152	145	50-12	....	28	.....	.....	30-4	46-12	.....	39-2	46-2
32	50	49	160	152	120-6	....	....	32	.....	.....	.....	29-8	.....	30-1	1-6
36	100-3	....	169-6	156-4	....	....	....	36	.....	.....	.....	.....	.....	22-10	
40	131-2	....	....	....	....	....	....	40							
A.P.	175-1	....	....	....	....	....	....	A.P.							

Off-sets in inches and sixteenths measured from base and ℄.

draw and fair all lines to one-quarter or one-half scale. The mold loft uses the smaller scale drawing to produce a full-scale layout, off-sets being corrected to suit. The second method plans on no fairing being done in the drafting room, over-all dimensions only being furnished to the mold loft. Fairing, in that case, is completed on the mold-loft floor. The first method has the advantage that volumes, areas, and other pertinent data can be obtained readily from drawings, a more convenient arrangement for the mold loft, for the loft floor is quite crowded at the peak of its use. Reproduction of loft lines by contact printing may be a worth-while solution. Under those circumstances, it may be that laying down of lines should be delegated to loftsmen attached to the drafting room so that designers can effectively control the form of the airplane and obtain essential information without delay.

Hull and Float Lines. Knowing the general form and principal dimensions, the designer can develop the lines of the hull from previous experience, coefficients, and trial and error. These lines are developed to one-quarter or one-half scale, three views being worked simultaneously. In some cases, previous designs are scaled up or down to suit the new design. In other cases, lines are developed from models that have been built and tested. Any linear dimension is proportioned to the cube root of the volume; *e.g.*, $\frac{l}{l'} = \sqrt[3]{\frac{V}{V'}}$. The result is a line drawing showing the body plan (fore-and-aft view), the half-breadth plan (plan view), and the profile, or sheer plan (side elevation). Plate III is an example of a drawing developed in this way.

Because sections produced by planes are indicated in all views, it is possible to reproduce the half breadth and profile from the body plan by development. The drawing furnished being to scale, it is necessary for inaccuracies in fairing to be removed. A corrected table of molded off-sets is the result of full-scale fairing of lines. This is the loftsman's first contact with the airplane to be constructed.

Before proceeding, it should be mentioned that by the latest practice in airplane manufacturing it is contemplated that line development in the drafting stage should be omitted. In accordance with this method, line drawings consist of sketches of nose and tail portions and of sections at stations, principal

dimensions only being given in each case. From this the loftsman develops the lines to full scale and establishes a complete table of off-sets or of dimensions. An example of a dimensioned body section for one station is given in Fig. 47. Given for several stations in a hull, it serves the same purpose as a line drawing.

Referring again to Plate III, we have a body plan showing sections at stations from the forward perpendicular to the after perpendicular. These sections are planes uniformly spaced perpendicular to the base line. The body plan indicates water planes parallel to the base line and perpendicular to the centerline plane. Water planes are uniformly spaced from the base line to the deck line. They are designated WL (water line) in the drawings. Also, in the body plan there are indicated bow lines and buttock lines. These lines are essentially planes equally spaced from the center line (℄) to the chine, being parallel to the centerline plane. The body plan shows bow sections on the left and stern sections on the right. Sections are numbered; water-line numbers, bow-line numbers, spacing dimensions, and over-all dimensions are given.

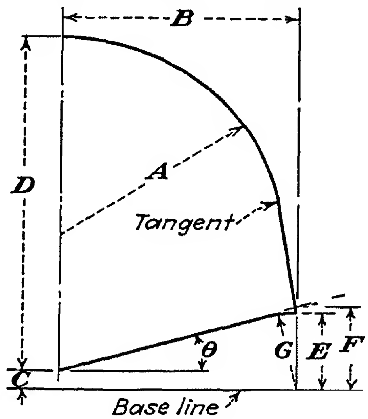

FIG. 47.

In the profile, stations appear as vertical planes perpendicular to the centerline plane. Bow and buttock planes cutting the hull appear as contour lines. These longitudinal sections can be understood if we regard them as sectional lines where the bow and buttock planes meet the hull shape. Water lines appear as planes perpendicular to the centerline plane and parallel to the base line. The load water line (LWL) for the normal weight is shown in this view. Owing to trim conditions assumed to exist, this LWL may not be parallel to the construction WL's. The stations may or may not be the frame and bulkhead locations. Frames and bulkheads are usually perpendicular to the base line, but their spacing is adjusted to meet strength requirements to which stations need not conform. The profile also gives station spacing dimensions and over-all dimensions.

In the half-breadth plan, we see the contour of the water-line planes and the chine line. Bow and buttock lines are parallel to the centerline plane. Stations are perpendicular to the centerline plane, appearing as straight lines equally spaced. Although the half-breadth plan ordinarily shows only one side of the center line, convenience may require that one side show water lines of the hull bottom intersections and that the other side show water lines of the deck intersections. This method prevents confusion of lines.

In general, the following statements may be made about lines: All contour lines are to the inner side of the plating and to the frames and longitudinals at their outer flanges. All contour lines are smooth and fair, chines, knuckles, steps, keel lines, and deck lines being terminals. Were it not for the expansion and contraction of paper, the off-sets could be taken directly from the curves. A table of heights in the body and profile plans, together with off-sets in the body and half-breadth plans, gives dimensioned positions of points on the curves. Dimensions may be accurate to $\frac{1}{16}$, $\frac{1}{32}$, or $\frac{1}{64}$ in. Dimensions are given in feet and inches or in inches.

Our purpose in handling stations, water lines, bow lines, and buttock lines is to develop a shape. This can be realized if we were to imagine section lines to be very close together, *i.e.*, the spacing reduced to small dimensions. In that case, we could almost see the shape forming by moving from section to section. The use of close spacing of stations, water lines, bow lines, and buttock lines is resorted to where curvature is great. True shape can be developed only where enough points on the curves are available so that all variations are indicated. Where lines are straight or fairly so, wide spacing of points is logical, for deviations are not likely to occur.

We shall now follow through a point on the drawings described, to show how the three plans work together. Let us take a point P on the surface of the hull at station 7 near WL-1 (in the profile, Plate III), following up the line representing station 7 into the half breadth until it meets WL-1 in that view. Note that it is near bow line $1\frac{1}{2}$. In the body plan the point P is indicated where WL-1, station 7, and bow line $1\frac{1}{2}$ cross. From the student's knowledge of descriptive geometry, it can be seen that interdependency exists in three views such as those shown in

Plate III for an object. Any one view has two dimensions to locate a point on that plan. However, the three plans give three dimensions essential to locating the point with respect to three axes, the forward perpendicular, the base line, and the center line being used as the axes.

From the information given to the loftsman, he produces an accurate set of lines and off-sets to suit by laying off the lines to full scale on the mold-loft floor, fairing the lines as he proceeds.

The loft floor may be a wood floor, a metal panel used as a floor, or some other suitable area. A planked floor, planks being narrow to prevent warping, is perhaps the best medium. Planks are set so that sanding can be used to erase lines. Of course, the area must be smooth and even. Flat gray paints are employed as mediums on which to work.

In certain cases, it is not necessary to lay out the whole length of the hull in the profile and half-breadth views. Under such circumstances, metal sheets painted white, ground glass sheets, plastic sheets, or some flat medium with a low coefficient of expansion and with small tendency to moisture absorption is convenient and practicable. The body plan to full scale is not too large for such sheets; and because it is ordinarily a permanent record in any case, it is best to work the body plan directly on metal, glass, or suitable plastic sheets. Where sheet size does not permit laying out the whole, left and right halves or forward and after portions can be put on separate sheets.

The loftsman commences with the body plan. The base line and center line are established. Vertical lines are drawn in at a distance apart equal to the molded breadth of the hull. Next we draw in the various water lines, equally spaced, numbering them from the base line up. A line parallel to the water lines and above the base line by a distance equal to the molded depth is drawn in. This is the deck line. The bow and buttock lines square with the base line are drawn in. They are numbered B-1, B-2, etc., from the center line (℄) out. Water-line and bow-line spacings are marked in inches. The line to coincide with the dead rise is struck in. If the deck line is straight in any part, the straight part is struck in. We now have all the straight lines of the body plan in place.

We now turn to the profile. The base line is established. The molded depth will give the location of the deck line above the

step station. The stations are located and station lines drawn in place square with the base line. If possible, the step should be on a station. Water lines parallel to the base line are drawn. We now commence to draw the curves to be faired. From the table of off-sets, we determine the height of the keel line above the base line at each of the stations. These distances are laid off with a rule on the proper stations, and there results a series of points along the length of the profile. Fair in the keel line with battens. At the steps and tail, use straightedges if these are straight lines. Next, spot the chine line and the deck line in the profile by taking dimensions from the table of off-sets. Likewise, the knuckle is drawn in the profile.

The half breadth is prepared by drawing the center line, the bow lines, the buttocks, and the stations. These are numbered and dimensioned to correspond with the body and profile. By taking dimensions from the table of off-sets, the chine can be drawn in the half breadth. Steps are located by squaring up from the profile. It will be noticed in Plate III that both sides of the center line in the half breadth are used for water lines. This is done for clarity.

By taking distances from the table of off-sets, each of the water-line curves can be developed. Points from the table, together with a judicious fairing of the line, give a water line. Be careful to number the points and the lines. Similarly, the curved buttocks can be drawn in the profile.

Returning to the body, we can establish station sections by taking dimensions from the half breadth and the profile. As an example, in the half breadth, from the center line on a station take off the distance to the first water line that the station line crosses. On the body plan at that water-line level, lay off that distance. This gives a point. In the half breadth, again on the same station, take off the distance to the next water line. Lay this off on the body plan at the appropriate water-line level. Do this for all the water lines crossed by that station line. In the profile and on the same station, take off the distance the keel is above the base line. Lay this off in the body plan on the ℄. In the profile again and on the same station, take off the distance base line to the first bow line. Lay this off on the body plan on the appropriate bow line. Do this for the other bow lines, the chine, and the deck. In the body plan, we now have a

number of points that establish the station section. The same procedure is followed for each station section, curves being drawn fair in the body plan to represent the station section. If all is well, curves will require little or no adjustment. Let us assume that no adjustments are necessary while we give a brief discussion of the fairing of lines.

Fairing and its derivatives are words that continually apply to lines. A fair line is pleasing to the eye, has continuity without abruptness, and gives a graceful form. It can be shown that, when buttocks, bow lines, and deck line in the profile, chine, water lines, and knuckle in the half breadth, and station sections in the body plan are continuous curves without abrupt direction changes, the lines are faired. As a matter of interest, diagonals or the intersection of the hull with any plane will produce a smooth curve when projected if the shape has been faired. If one runs his hand over the surface of a model, fairness of form can be felt. Changes in direction are smooth and regular, no hollows or humps being noticed. This results from faired curves in all intersecting planes.

In drawing a curve to fit established points, stiff battens should be used. Where a long line has curves of long and short radii, the batten can be lightened where the radii are short. Fixed curve forms, made for the purpose, are useful in giving true fairness when they can be made congruent with the points concerned. Usually, fixed curve forms are limited to small-radii curves.

It is to be noticed in fairing lines that lines which represent planes that are most nearly square to the surface intersected are the best for fairing. They give the nearest true form of the hull and, for that reason, show the amount added or subtracted for fairing most accurately. The buttocks and bow lines for the ends, the water lines for the sides, and the diagonals for longitudinal turns are representative examples.

Increases in the number of sections or lines will give more points on the curves, and the result is better control of the fairing where the curve must be more closely examined. It is customary to increase the station sections at the bow. Advantages may result from increases in bow lines, also.

In any case, fairness can exist in the hull only if the primary curves are fair and provided that the projected curves are fair

and project accurately. That is, points must fall on curves in all views. Deviations must not exceed the tolerances in any case.

To return to the adjusting of lines, after the body-plan sections have been drawn in, it will be noticed that some points taken over from the profile and half breadth do not fall exactly on the curves. Using the body-plan sections, take the new points back to the profile and half breadths, and reestablish new water lines, bow lines, and buttocks. By working back and forth from the body to the profile and half breadths, all curved lines should agree in all three views. Large adjustments are not required ordinarily; if they are, something important is in error and new basic lines may be necessary.

Clearly, projection of a point in three views is simple. A straight line projected in three views is also easy to accomplish. Projecting a curve may or may not be easily done, depending on circumstances. In fairing lines such as those with which we are concerned here, we are establishing the regularity of a curve and at the same time we are projecting it in three views. This establishing of the fairness, smoothness, or regularity causes difficulty because movement of a part of the curve in one view affects another view. However, a process of trial and error is the only practical means readily available until experience becomes a better guide. Experience will also indicate that regularity and fairness of lines produce a faired surface.

There are ready means for checking the fairness of a surface by lines other than those referred to so far in this discussion. Of those, the most common is the diagonal. The diagonal comes from the shipbuilding loft where it is drawn in the body plan diagonally from the center line through the ship's side. A bilge diagonal goes through the bilge of the ship. Where the curvature of the hull is such that it has small radii running along the length of the hull, the use of diagonals is advisable. One example will suffice.

In Fig. 48, AB is the diagonal plane set at an angle with the centerline plane. It is apparent that the trace of the diagonal plane with the profile plane and the half-breadth plane is straight in each case. The intersection of the molded surface and the diagonal is curved in the profile and half-breadth views. It can be shown in either. In the figure, we have chosen to show it in the profile. Distances Aa, Ab, Ac, etc., are laid off on the appropriate

stations, establishing the points a', b', c', d', etc. This is the diagonal intersection. It will be noted that the true shape has been shown by turning the plane on an axis through A into the centerline plane.

We could have used horizontal ribband lines. Laying off the horizontal measurements of ma, nb, pc, qd, etc., on the half-breadth plan would give spots through which a curve can be drawn. This is a test of fairness equal to that afforded by the true diagonal curve.

Fairing by the contracted method has its important uses. Where curves are long and sweeping, it is very difficult to fair a

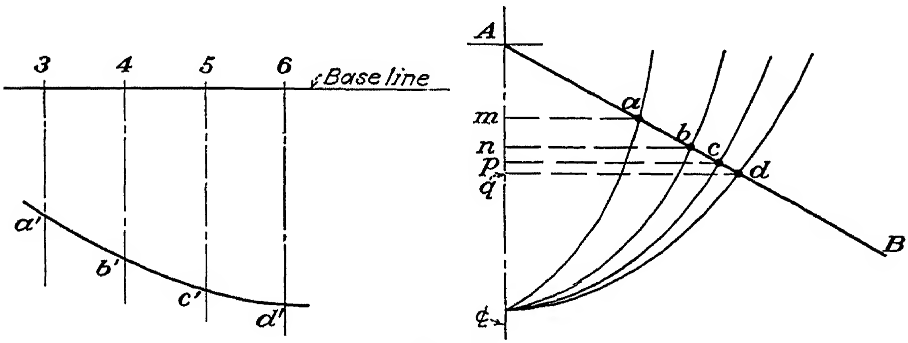

Fig. 48.

curve with battens. To overcome this difficulty, it is customary to contract the stations to one-third or one-fourth the actual spacing. Contracting fits into the profile and half breadth for the portion on each side of the step where curves are shallow. Contracted fairing gives sharper curves, permitting the batten to hold a shape to better advantage. Stations being laid off to some fraction of full scale, the water lines, bow lines, and buttocks are laid off and drawn in. The resulting curve can then be used to get off-sets for use in the normal profile and half-breadth plans.

This fairing of lines may result in corrections in the body lines. As before, it is necessary to work between body and profile and body and half breadth until the lines are correct and projections fall on the lines in the other views.

When the lines have been completed, the off-set tables are corrected by measurements made on the full-scale layout. This

becomes the record to which all questions regarding lines are referred. It serves also as the permanent record for future use when duplication is necessary.

There are special circumstances surrounding the fairing of lines at the bow and the stern of ships. Sometimes these same factors are of importance in handling hull and float lines. As hulls are increasing in size, the similarity to ship construction is apparent. Some discussion of laying out lines at the bow will be given at this point.

Ships have a stem casting as the forward terminal of the hull. Flying boats depend on a plate-and-angle construction in some cases; in others, the use of an extruded shape has advantages. The problems present some analogies in either case.

In considering a hull or float bow, there are two features that need special attention. The first has to do with the general shape of the bow. In order to handle this, we rely upon the use of extra stations and bow lines. The number can be determined by the loftsman; $\frac{1}{4}$, $\frac{1}{2}$, 1, and $1\frac{1}{2}$ extra stations and the same number of extra bow lines ought to be sufficient. Other than the increased number of lines to get additional points for the curves to be faired, the bow constitutes the same problem as does the fairing of lines in general. Contraction at the bow is not necessary.

The second matter that calls for special consideration has to do with the fairing necessary to close in along the keel and the stem. The stem and the keel may present widths that vary considerably. Full-scale use of bow lines close to the center line will give information essential to fairing keel, stem, and plating.

In Fig. 49, A is on the center line, and B is off the center line by the half thickness of the stem extrusion. Draw XX' to represent the centerline plane. From XX', we lay off the half stem at the appropriate water lines. On the half-breadth plan, we can lay off the half keel parallel to the center line to station 2. From XX', we can get the half stem which can also be laid off on the half-breadth view. The points resulting are r and s. Working from the body plan XX' to the half breadth, we can fair in the junction of the stem and the keel. Although the above case looks realistically like straight-line construction, cases developing distinct curves may be met where the above procedure will give the desired results.

The check is to lay off the B-½, B-1, B-2 lines in the profile from the intersections in the body and in the half breadth. If the resulting curves fall on the points taken off, fairing can be expected.

It is sometimes necessary to fair lines to some inner portion of the hull. If the distance is small, this can be done by using construction lines perpendicular to the water-line curve in the half breadth at the point under consideration. Measure in on this perpendicular the distance established, which gives a point.

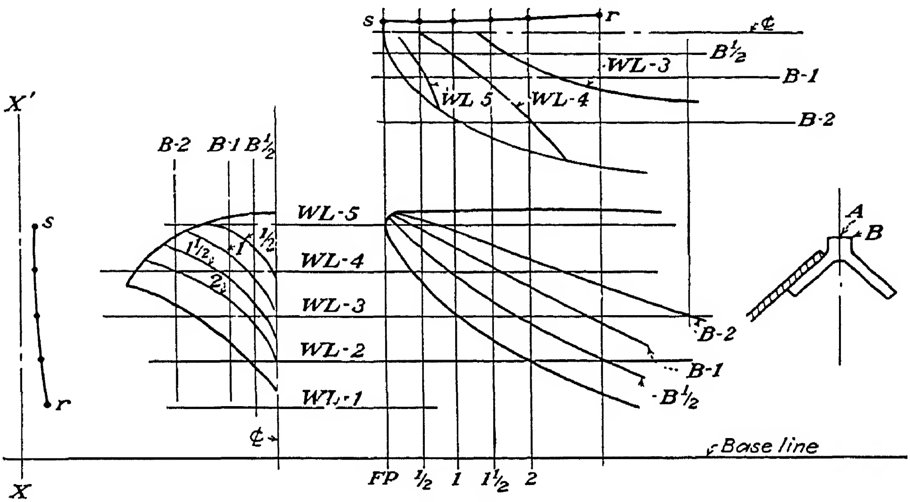

FIG. 49.

Through this point, draw a line parallel to the station lines, cutting the water-line curve again. It can be seen that this is the sectional distance which, in turn, can be laid off in the body plan to get the inner-section point. Several points so laid out will give the inner curve.

If the distance to the inner portion is large, it will be necessary to locate the position of the inner portion by bringing the sections in the body inward along diagonals normal to the section curve. Fairing by several diagonals handled in the normal manner will give means for true traces, with resulting curves accurately placed.

The net effect of laying off the hull lines on the loft floor has been to obtain an accurate set of lines, properly faired, ready for further uses in making templets, forms, etc. A record of the

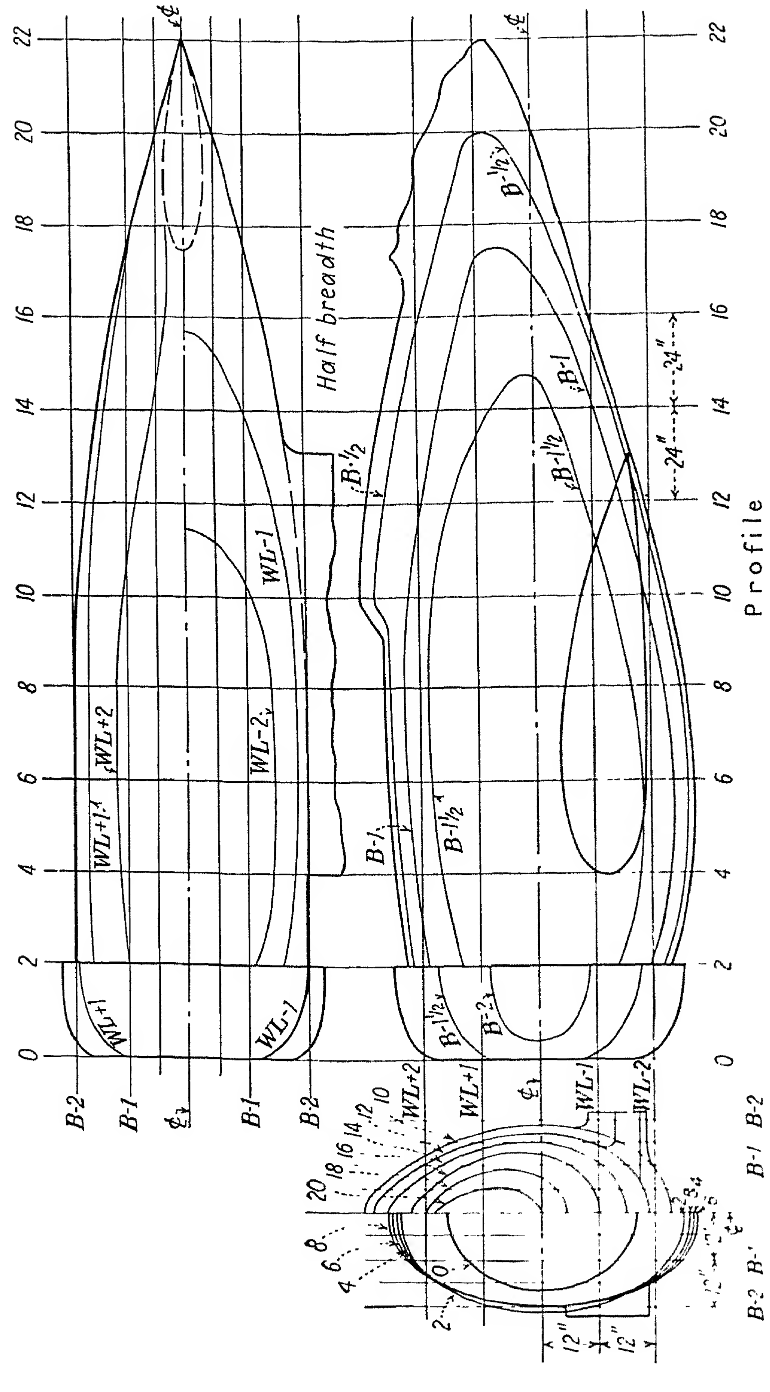

PLATE IV.—Fuselage lines.

Molded Off-sets

Sta.	Profile Heights: Vert. ℄		B-½		B-1		B-1½		Sta.	Half Breadths: Hor. ℄	WL + 1	WL + 2	WL-1	WL-2
0	+21-3	−21-3	......	......	......	......	+10-0	−10-0	0	21-3	13-0	.....	13-0	
2	+30-2	−30-2	+27-1	−27-2	+23-2	−24-0	+21-8	−21-8	2	28-11	23-8	12-0	23-8	13-8
4	+29-9	−31-5	+28-9	−30-6	+26-8	−28-1	+20-0	−21-6	4	24-0	20-0	14-0	24-8	17-7
6	+31-7	−34-9	+30-0	−31-9	+27-10	−29-2	+22-2	−22-0	6	24-0	20-0	15-1	22-1	17-12
8	+32-1	−31-8	+31-1	−30-0	+28-0	−27-6	+22-9	−20-0	8	24-0	20-0	15-0	22-0	17-5
10	+38-6	−28-2	+34-2	−27-8	+27-12	−23-3	+21-8	−16-9	10	23-1	19-9	13-6	21-1	13-0
12	+36-2	−23-1	+32-0	−22-0	+24-0	−18-7	+17-4	−10-8	12	21-10	19-1	10-8	17-9	
14	+32-5	−17-13	+28-5	−17-10	+20-0	−12-1	+ 8-2	− 4-8	14	19-0	17-8	7-10	11-10	
16	+28-12	−12-2	+24-1	−10-0	+16-1	− 5-9	......	......	16	16-2	14-2	4-0		
18	......	− 7-0	+19-0	− 2-14	......	......	......	......	18	11-3	10-11	4-1		
20	......	0	+10-0	......	......	......	......	......	20	5-14				

Off-sets in inches and sixteenths measured from horizontal and vertical ℄.

lines by molded off-set recordings or by contact printing will establish the permanency of these lines.

Fuselage Lines. Compared with hull lines, fuselage lines are generally simpler. The curves are uniform along the length, contraction in size occurring in three dimensions. But even though the fuselage lines appear to be self-evident and simple, the loftsman should not be tempted to omit laying down the body, profile, and half breadth to full scale to check the off-sets. This operation corrects small-scale drawings, permits fairing lines smoothly, and furnishes the bases for templets, jigs, and forms.

At this point, it might be well to describe some special procedures in loft practice, used when circumstances warrant. If the loft area does not permit full-length profile and half-breadth views, portions along the middle of the length of the fuselage where sections do not change may be omitted, the nose and tail portions being brought close together. Also, where confusion will not result, profile base line and half-breadth center line coincide and the bow, buttock, and water-line curves fall in the same area on the loft floor. If prints of these are necessary for later work by several groups of men, apparatus is now available for making duplicates to exact scale. Prints can be made on transparent plastic and transferred to wood, metal, paper, etc. There will be complete explanation of these processes in Chap. VI.

Another practice that may save the loftsman time is to note a sectional change that is uniformly changing at the same rate along the length. Where this occurs, he can use proportioning dividers effectively. The proportioning dividers are in the nature of an adjustable "X," the axis being set to give a constant proportion between the upper and lower spans.

In Plate IV, there are shown the typical lines of a fuselage. The student will recognize the body, profile, and half-breadth views as being much like those of a hull line drawing. The vertical center line in the body plan is in the same location. To take the place of the base line in the profile, we use a fore-and-aft line through an axis of symmetry more or less near the center of the fuselage. This line is ordinarily known as the *horizontal center line.* It may or may not coincide with the thrust line. It usually exists at the location of maximum beam width. Water lines are parallel to the horizontal center line, placed above and below the centerline plane and marked plus (+) or minus (−).

The off-set tables prepared in the drafting room for the fuselage give the basis for laying out the fuselage lines on the loft floor. All work is handled in exactly the manner described with reference to hull lines. There are some advantages in working fuselage lines; for many fuselage lines are circular arcs, and fairing, therefore, is simple. On the other hand, where fuselage and wing and tail surface lines merge, there are special difficulties requiring great care in making the fillets fair properly.

Off-sets for water-line curves to be plotted in the half breadth are given as single dimensions from the vertical center line for the station and water line concerned. Although each water line intersects the fuselage symmetrically right and left, only one side needs to be faired. Off-sets for bow lines and buttocks to be plotted in the profile view require two dimensions for each station and each buttock. Bow lines and buttocks cut the fuselage above and below the horizontal center line. Consequently, points on a station are given as plus (+) and minus (−). The fuselage is hardly ever symmetrical above and below the horizontal center line. Buttocks beyond the molded breadth will cut the lower part of the fuselage only.

The vertical center line being the "O" buttock, we have bow lines and buttocks to left and right of this line, equally spaced and parallel. Bow lines and buttocks are provided to a point beyond the center-section panel.

Station lines in the profile are normal to the horizontal center line. For fairing of lines, it is best to space station lines equally, although the location of station lines at frame stations is not unusual. Frames are invariably perpendicular to the horizontal center line. Fuselages being symmetrical right and left, the profile with bow lines and buttocks indicated is sufficient for fairing purposes.

In the half breadth, there would be much confusion if we tried to show all the water-line curves on one side of the center line. It is the practice, therefore, to place the upper water lines above the center line and the lower water lines below the center line.

Where the fuselage lines take the form of circular arcs, it is not unusual to have the off-set tables give the locations of the centers and the length of the radii. This facilitates layout materially. Adjustments may be necessary.

Where the fuselage lines merge into the wing and tail surfaces, we have a special problem. The fillet itself may take the form

of a circular arc, but the centers do not hold to a simple form. Under these circumstances the loftsman will find it advantageous to use diagonals for fairing these intersections. Figure 50 represents some station lines as viewed in the body plan. At this point, there is intersection with the wing trailing edge. By the use of a diagonal, as AB, we can lay off Aa, Ab, Ac, etc., on a plane parallel to the horizontal center line. Plane AB is turned about axis A. Fairing this diagonal intersection, we can definitely establish a, b, c, d, etc., to produce fairness. More diagonals will improve the fairness of the intersecting surfaces, giving a good fillet and serving to establish the points of tangency.

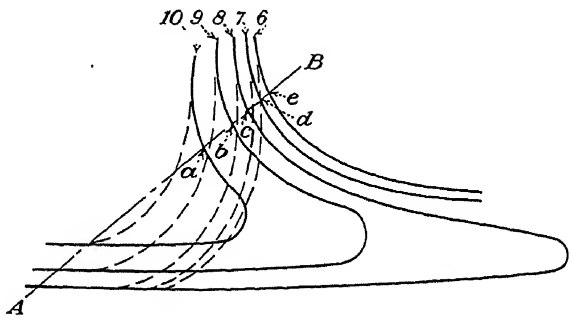

FIG. 50.

The lines of the cabin enclosure may be combined with the fuselage lines where its position, size, and shape warrant. Otherwise, it can be faired as a separate unit and connected to the fuselage by locating the intersection of surfaces and fairing in the intersections. Some parts of the pilot's cabin may be single-plane surfaces. Where this occurs, it is advisable to project these plane areas onto planes set at angles, with stations and center lines truly indicated. This can be done by turning planes about traces until true lengths can be shown. Where the cabin enclosure as a whole is set at an angle with the horizontal center-line plane, it may be best to fair it by itself on lines parallel and perpendicular to its own axes. After this is done, its position as a whole on the fuselage can be established. Here again, diagonals will assist the loftsman in fairing and in producing traces for the intersections.

It is frequently necessary to take into account fuselage openings. Bomb doors, landing-gear housing, and similar items

require cutting into the fuselage. These openings may be incorporated in the line drawings for convenience. The true lengths of opening lines can be established in the views available, or new planes may be used by swinging diagonals about traces in the half breadth or profile.

Longitudinal stiffeners, sometimes called "longitudinals," in the fuselage extend fore and aft more or less square to the frames. The fuselage line drawing frequently includes traces of these longitudinals. They are not necessary for the loft fairing of lines; but because the loftsman must bear in mind the fuselage construction, it is as well to indicate their function in the line drawing.

Longitudinals, being practically square with the frames, may appear in the body as straight lines (diagonals) radiating from the intersection of the horizontal and vertical center lines. This is the case particularly where we have circular or oval sections. Where the section deviates from the circular, it is practically essential for the longitudinal curve to become nearly normal to the section lines. It is to be noted that the diagonals produced by longitudinals can be adapted readily to assist in fairing.

In other cases, longitudinals are run fore and aft as straight lines in the half-breadth view; in still other cases, the longitudinals will be found to be parallel or at a slight angle to the horizontal center line, being straight in the profile view.

Off-sets of longitudinals can be given in the tables by locating points of intersection (stations and longitudinals) from the horizontal or vertical center lines.

The engine cowling, whether in a nacelle or as a part of the fuselage, has a form usually circular in cross section. Cooling ducts, carburetor intake, etc., occur as faired openings in the cowling, but otherwise the fairing of lines is straightforward and simple.

When the engine is in the wing, we have a nacelle. The lines of a nacelle are handled like those of a fuselage. The thrust line is used as the horizontal reference plane. The main difficulties have to do with fairing the nacelle into the wing. Here, again, the loftsman will find the use of diagonals a distinct advantage in producing the desired fillet. It might be mentioned that fillets may be very small where aerodynamics have indicated that large fillets cause increase in drag. The wind-tunnel tests have

done much to show that the airflow along the filleted surface has special characteristics.

After all lines of the fuselage have been faired and are in order, the table of off-sets is corrected and becomes the record for fuselage lines.

Although the foregoing is applicable to any type of construction, it is more appropriate to semi-monocoque structures. Where we have a truss structure inside (such as a welded-steel-tube type) with formers to produce the curved shape outside, we may encounter a special circumstance. It is advisable in such cases to include a lay-off of the lines of the main truss members so that the relative positions of truss and outer surfaces can be studied carefully. The added lay-off will be of much use in producing templets, jigs, and forms. Also, of more importance perhaps, it will show that the outer lines encompass all parts of the truss structure.

Wing and Surface Lines. The principles involved in laying off the lines for fin, rudder, stabilizer, and elevator are the same as those applied in laying off the lines for the wing. In each case, we are dealing with a structure wide, long, and thin, with all three views involving curved surfaces. These surfaces are not regular developments. Ailerons and flaps, being parts of the wing, are part of the wing drawing. Tabs inset in elevator and rudder are treated as part of the larger surfaces. To avoid repetition, we shall limit ourselves to a discussion regarding the laying down of wing lines only.

There are several ways of presenting data on wing lines to the loftsman, depending on the practices obtaining at the various airplane manufacturers' plants. In Plate V, a good example of complete data is shown. An addition that might have been beneficial would have been the inclusion in the drawing of airfoil profiles along the span of the wing. The data for profiles are tabulated in this particular case.

We must regard a wing panel as securing to a fuselage off the fuselage center line with dihedral. The wing may taper in chord, taper in thickness, or have a sweepback leading edge or a sweep-forward trailing edge; or it may be characterized by any combinations of these forms. The wing-tip plan form may be elliptical, square, or circular. The wing may secure to the fuselage, to a center-section panel, or to the wing on the opposite

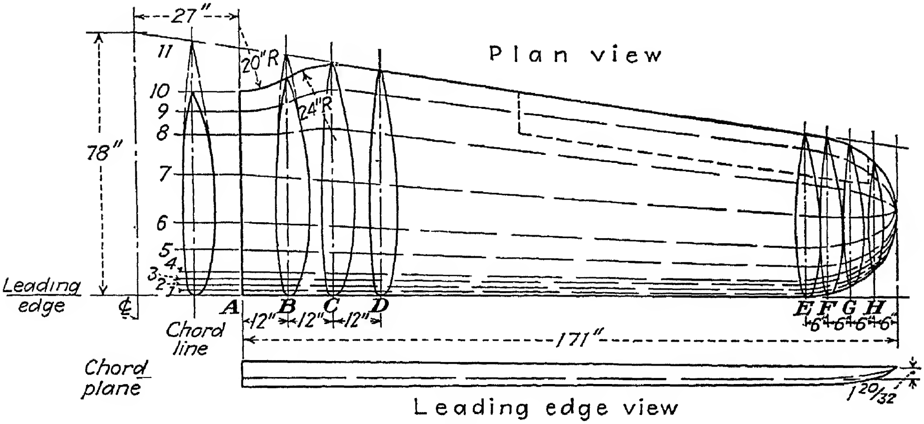

TABLE OFF-SETS

Section A

Sta.	Dist. L.E.	Upper	Lower
1	1-24	1-22	−1-0
2	3-0	2-16	−1-3
3	5-0	3-8	−1-15
4	7-8	4-2	−1-24
5	14-6	4-28	−2-10
6	22-2	5-2	−2-16
7	36-3	5-2	−2-16
8	48-7	4-0	−2-0
9	55-5	2-0	−1-3
10	60-0	0-3	−0-1
11	75-0	...	.....

L.E.R. = 24/32
T.E.R. = 5/32

Section B

Sta.	Dist. L.E.	Upper	Lower
1	1-20	1-18	−0-28
2	2-26	2-8	−1-0
3	4-24	3-1	−1-10
4	7-0	4-0	−1-20
5	13-4	4-20	−2-3
6	21-2	5-0	−2-10
7	30-22	5-0	−2-10
8	49-0	3-28	−1-27
9	57-17	1-30	−1-1
10	64-15	0-3	−0-1
11	....	...	.....

L.E.R. = 24/32
T.E.R. = 5/32

Section C

Sta.	Dist. L.E.	Upper	Lower
1	1-16	1-14	−0-24
2	2-20	2-1	−0-28
3	4-16	2-26	−1-5
4	6-23	3-29	−1-15
5	12-10	4-12	−1-31
6	21-3	4-28	−2-5
7	34-14	4-28	−2-5
8	49-30	3-24	−1-24
9	61-4	1-26	−0-28
10	69-7	0-2	−0-1
11	....	...	.....

L.E.R. = 24/32
T.E.R. = 4/32

Section D

Sta.	Dist. L.E.	Upper	Lower
1	1-12	1-10	−0-20
2	2-14	1-27	−0-24
3	4-8	2-23	−1-0
4	6-25	3-25	−1-10
5	12-16	4-6	−1-26
6	20-2	4-24	−2-0
7	33-1	4-24	−2-0
8	48-7	3-20	−1-21
9	59-28	1-22	−0-24
10	67-17	0-2	−0-1
11			

L.E.R. = 23/32
T.E.R. = 4/32

Section E

Sta.	Dist. L.E.	Upper	Lower
1	1-7	1-0	−0-16
2	2-1	1-20	−0-20
3	4-3	2-10	−0-28
4	5-18	3-0	−1-0
5	9-8	3-16	−1-10
6	15-2	3-28	−1-20
7	24-15	3-28	−1-20
8	33-7	3-0	−1-3
9	45-2	1-2	−0-16
10	48-0	0-2	−0-1
11	...	..	.....

L.E.R. = 14/32
T.E.R. = 2/32

Section F

Sta.	Dist. L.E.	Upper	Lower
1	1-4	0-28	−0-15
2	1-27	1-16	−0-18
3	3-31	2-5	−0-25
4	5-16	2-27	−0-28
5	9-0	3-10	−1-5
6	14-15	3-12	−1-14
7	23-4	3-10	−1-13
8	32-5	2-28	−0-28
9	43-0	0-29	−0-14
10	47-16	0-2	0
11	..	.	....

L.E.R. = 13/32
T.E.R. = 2/32

Section G

Sta.	Dist. L.E.	Upper	Lower
1	1-0	0-24	−0-14
2	1-23	1-12	−0-16
3	3-30	2-0	−0-22
4	5-14	2-22	−0-24
5	8-0	3-5	−1-1
6	13-3	3-6	−1-8
7	21-0	3-5	−1-6
8	28-7	2-24	−0-23
9	37-12	0-24	−0-12
10	42-0	0-2	+0-1
11	..	.	.....

L.E.R. = 13/32
T.E.R. = 3/32

Section H

Sta.	Dist. L.E.	Upper	Lower
1	0-24	0-20	+0-1
2	1-3	1-8	−0-4
3	2-28	1-27	−0-8
4	4-3	2-10	−0-16
5	6-14	2-15	−0-28
6	10-18	2-16	−0-31
7	16-16	2-14	−0-28
8	22-3	1-28	−0-14
9	28-0	0-20	0
10	32-2	0-1	+0-1
11			

L.E.R. = 10/32
T.E.R. = 3/32

Offsets in inches and thirty-seconds measured from section chord.

PLATE V.—Wing lines and offsets.

side. The wing may have cutouts near the wing root. The wing may have washout or washin. All these factors are of concern to the loftsman. He should study the data on which he is to base his lines carefully, for aerodynamic features incorporated in wings are small in size and easily overlooked. Here, again, it is very important that the loftsman secure a high degree of accuracy in laying down the lines.

Wing sections are essentially airfoil sections that have been tested in wind tunnels to determine their aerodynamic characteristics. In a particular wing the same airfoil exists from wing root to wing tip. However, the size of the section may vary considerably. Excepting for the parts of the wing near the root and the tip, the change in section size is ordinarily uniform.

The loftsman lays off wing lines with reference to the chord line, the leading-edge reference line, and the wing-root line. These lines may or may not concur with the reference planes used in the fuselage lines. For instance, the wing as a whole is set to produce dihedral angle and angle of incidence.

Terms designating the views are not standardized. Here we shall designate the views as sections giving profiles, leading-edge view, and plan view. It is usual to lay down the reference planes first. The leading-edge reference plane is square with the fuselage vertical center line. The wing-root plane is square with the leading-edge reference plane. We can now lay down the plan-view form of the wing. The leading edge and the trailing edge are struck in, these lines being straight and at definite angles with the reference planes. On this same plan view, we establish the sections, usually equally spaced, with intermediates at root and tip as may be necessary. These sections may agree with rib locations.

The plan form of the wing is easily established by straight lines and circular arcs. Therefore, we are interested in the contour of the upper and lower surfaces of the wing and with accurate fairing of this form within the plan form. In the off-set table, we shall find recorded the data necessary to establish the points for certain sections. The data for establishing the form at other sections will be described later. At a section such as *B* in Plate V, there is recorded leading-edge radius, trailing-edge radius, distance of station from leading edge, and the upper and lower camber ordinates at each station. The station's distance from leading

edge has been calculated from airfoil data which give this distance as a percentage of the chord from the leading edge.

Now, we lay down the section profiles for each section. Chord line and station planes are the references. Profiles can be laid down on the plan view by using the section line and chord line

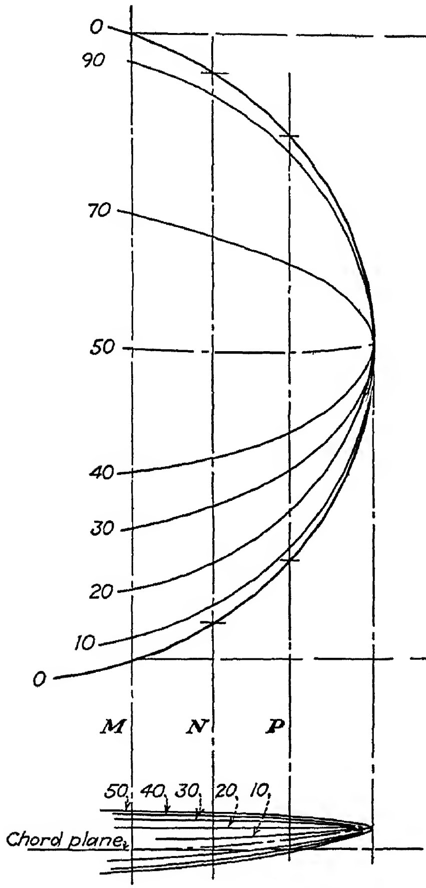

Fig. 51.

concerned, in coincidence. Plotting the ordinates given in the off-set tables will give the contour of the wing at the section concerned. Ordinates of upper and lower cambers above and below the chord line for the section at a station give the spot locations. Lower cambers may go above the chord line, depending on the airfoil being used. Curves of upper and lower cambers

are faired with battens. The leading edge and trailing edge are usually circular arcs.

The drawing and data from which the loftsman works will not give data on sections where the wing is uniformly changing or where it is held constant. Where it is changing at a uniform rate, the loftsman can interpolate or he can take section measurements from the leading-edge view. Plotting known section measurements from the plan view to the leading-edge view will permit the loftsman to spot any ordinate desired on any section and station between the known sections. The mold-loft lay-off of the wing should include all sections along the span so that data on form will be readily available.

The chord plane (Fig. 51) is the reference line in the leading-edge view. Section planes are square with this plane. The plot

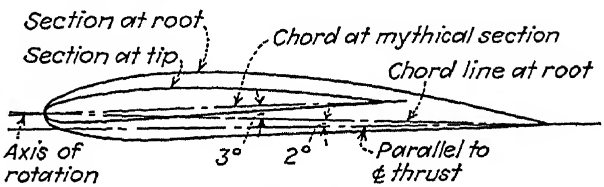

Fig. 52.

of station-plane intersections in this view will permit the fairing necessary to bring section curves and station curves into conformance. They are faired as curved water lines and curved buttocks are faired. Adjustments may be necessary to produce the desired fairing.

The wing tip constitutes a special problem in that the chord plane deviates from the straight line. The drafting data are usually based on half-scale information. The loft must use full scale or larger for fairing, getting the data into full scale for templet making. Nothing extraordinary is required of the loftsman in fairing the wing tip; care and accuracy, of course, are needed, as always. The tip is faired in working the three views shown, until station intersections and sections are fair in all views. The stations are percentages of chord (all necessary are not shown) and are increased in number near the leading edge. Diagonals (not shown) can be used to complete the fairing.

Where we have washin or washout, the net effect is that the wing has been given a twist through some small angle so that the chord line is neither in the same plane nor parallel to other chord

lines throughout the span of the wing. The center of twist may be the leading edge, the trailing edge, or the aerodynamic centers. By extending the straight leading and trailing edges to the extreme wing tip, we can construct a mythical section. This section has the chord line set at 3° with the chord line at the root which is the washout of incidence (see Fig. 52).

Wash may be applicable to one panel (right or left) only. In that case, right and left panel lines will be laid down, for one is no longer the mirror of the other. In laying down the wing lines where we have wash, it is necessary that each section shall be plotted with its chord line set at an angle, the angle increasing from 0° at the root to the wash angle at the tip. Sections having

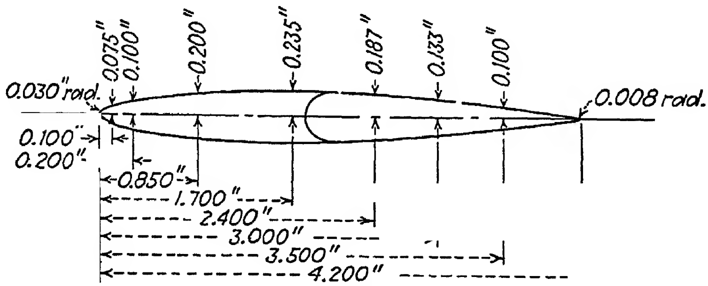

FIG. 53.

been faired, station intersections are faired, and thence we proceed in the normal manner.

Having faired sections and station intersections of a panel, corrected off-sets are tabulated for the record. These become the record of the wing lines for future use.

Figure 53 shows a typical method of recording off-sets of an elevator-stabilizer surface. Note the symmetry of the upper and lower cambers.

The full size being small, it is practicable to lay such lines down in the drafting with no further fairing required.

After the wing lines or other surface lines have been developed, it is necessary to consider the auxiliary surfaces that fall within the main surfaces. For instance, flaps, slots, and ailerons come within the wing contour but require their own lines, to be complete. Fortunately, these additional lines are straight or effected with circular arcs so that development is simple. They do require a check on clearances, at the time that lines are faired, to permit operation to prevent later interference.

CHAPTER IV

MODELS AND SHELL EXPANSION

Models. Airplane models of the kind with which we are concerned are small-scale wood representations having a degree of accuracy commensurate with the service to which they are to be put. Hull and float models are for use in the model basin to determine the water characteristics of the flying boat or seaplane. Wind-tunnel models serve to give information regarding the anticipated behavior of the airplane in the air. Half models are exceptionally well adapted for studying the location of frames and longitudinals and the arrangement of the shell plating. Besides these, there is the display model which serves a variety of purposes, the principal one being that of study and discussion. All these models are made to different scales and according to different methods of construction but generally are truly representative. In each case the loft lines are followed implicitly so that there can be no occasion to question test data obtained from their use. In addition, it is a matter of pride that the model be a good representation, of excellent workmanship. Model building in itself has many of the aspects of an art.

Hull and float models for testing characteristics in a model basin are built specially for that use. The scale is determined by the length of the basin and take-off speed of the seaplane. Models may be 3 to 9 ft. in length when tests are to be run in a tank such as the National Advisory Committee for Aeronautics 2,000-ft. towing basin. The model is made of solid pine or mahogany (painted) to scale with the final loft lines. Because test results are on a small-scale model, it is necessary that the underwater part of the float model shall be made with a high degree of accuracy. Small errors in form can cause large errors in results when interpreted for the full-scale seaplane. Tolerances as low as ± 0.01 in. in the model are required. Ordinarily float models are not made to have any weight relation with the seaplane represented.

Balance, trim, and draft are regulated by applied forces. In some cases, it may be necessary to tow the same model with minor variations in the form of the bottom; for instance, several step types may be contemplated. In these cases the model can be built to have a demountable section with alternative replacement parts available so that the change can be effected without making a complete new model.

In order that information as to the stability, the lift, the drag, and other aerodynamic characteristics of an airplane design may be available without waiting for test flights of the actual airplane, a small-scale model is built for tests in the wind tunnel. The size of the model is determined by the size of the tunnel in which it is to be tested. Wind-tunnel models must be constructed very accurately with as small a tolerance as the model material will permit. They may be built of wood or soft metal such as brass or aluminum. All parts are correctly set with relation to the reference lines. Movable surfaces are arranged so that they can be adjusted and set within the ranges required for the airplane. The weight of the model bears no relation to the airplane weight, for this is neither necessary nor practicable. Reference lines, center of gravity, and other pertinent data are marked on the model to permit ready comparisons. If the model is to be tested with various types of wing, it is a simple matter to provide the model with removable wings so that substitutions can be made readily. The wind-tunnel operations with a model are of various kinds; they include tests at all angles of attack within the useful range of the airplane.

Display models take many forms and are made for various purposes, advertising, historical, and others. However, there are many instances where features can be studied by designers and others in the model stage to good advantage without making a complete airplane or a mock-up available. This is the case most frequently when new mechanisms must be portrayed or where relative positions of parts of the airplane cannot be pictured effectively otherwise. The display model is also helpful when special attention to design features is essential. Display models are made of wood, metal, or other convenient materials. Modeling clay sometimes serves where permanency is of no importance but where form or shape has to be studied in three dimensions to get the full effect of displacement.

The half model is not used extensively in the aircraft industry although it should serve effectively for arranging frames, longitudinals, shell plating, and other parts of the structure. Hulls, floats, fuselages, and similar units have relative dimensions that could be more readily discerned if a half model were used. Such a model can be built to any convenient scale at no great cost and without the high degree of accuracy usually essential in models. As will be shown later, under Shell Expansion, the half model is an extremely simple means for studying the arrangement of the shell plating. It also serves to indicate plating shapes where important compound curves are involved. Until an airplane gets into large production, models such as the half block are very important additions to shop drawings in structural-assembly shops. A quick glance at a model gives information that can be gleaned from the drawing only after prolonged study.

All models can be constructed in somewhat similar ways. The use of wood is universal because it is an easily worked material. Where sections are thin, cast brass or aluminum may be better. It is considered best to make the model by assembling wings, tail surfaces, landing gears, etc., to the fuselage or hull. A brief description of the method used in making a half model of a fuselage will suffice to show one procedure that has been followed.

The model is built in layers, each layer representing the distance between water lines as obtained from the body plan. Using boards of the correct thickness to represent the distances between water lines, we can plot on each board the water-line curve above and below. As an example, on a board, draw the vertical center line; using the half-breadth dimensions, plot and draw in the water-line curve; then, on the other side of the board, plot and draw in the next lower water-line curve. We now cut the board along the center line and just outside the larger of the water lines. For convenience, we may lighten the board by cutting out the inside portion.

Boards so cut and glued or pegged together will form the rough of the fuselage (see Fig. 54). Now by shaving off the model until we come to the water-line markings on the board, we shall approach the correct shape. The final operations may consist of sandpapering to produce the required fairing and the proper dimensions. Convenience may dictate that the model shall be constructed for a little more than half the fuselage so that the

center line will not land on the back board. An inch or more clearance or fill will be found advantageous. Half models are painted white for easy marking. Center lines and other reference lines should be scribed on the model.

Another method of making a model is to make half sections of wood, reproduced from the body plan. These half sections for each station are made undersize about ¼ in. They are mounted on a back board in proper position, representing somewhat the framing of the fuselage. The center line is a reference plane for mounting them accurately. Using battens slightly over ¼ in. thick, we cover the half sections. The battens are secured with screws and are fitted close together in the form of a sheathing. At the ends the battens are cut and fitted to the back board to suit. The screws are sunk so as to permit fairing the model to the correct dimensions. An outside mold made from thin wood and conforming to section dimensions serves as a gauge in thinning the battens to the correct shape at the section concerned. In all model work, allowances for plating thicknesses must be made to the dimensions taken from the line drawing. The model having been shaped, putty is used to fill openings and holes. Finish painting is applied as may be necessary. Various reference planes and centers can be scribed or marked as may be required. Stations are marked on the back board.

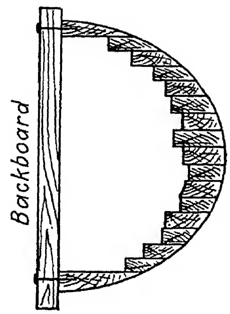

FIG. 54.

Shell Expansion. The skin, or shell plating, of a hull or a fuselage or, for that matter, any volume having curves in more than one dimension, requires more than ordinary care in determining how it is to be made to produce the best possible results. The first point to be decided is as to the arrangement of the plating. It is easy enough to determine the general layout, but study of the details may eliminate complications not otherwise evident. The usual procedure of chopping up shell plating into many little pieces is not warranted in this day when designers are trying to reduce drag with flush surfaces throughout.

In the half model, we have a simple means at hand for studying the arrangement of the shell plating. By means of the section station marks on the back board of the model, we can locate

the frames. A simple outside-section mold made a little larger than the largest fuselage section of the half model helps in laying in the frame lines on the model. This mold has a bracket secured to it so that it will stand square with the back board. It is set to the position of the frame to be scribed on the model, square with the back board and square with the horizontal

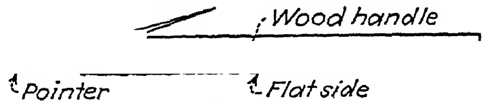

Fig. 55.

center line. The pen or pencil for marking has a flat side with the point in the same plane as the flat side (see Fig. 55). With the mold and this special pen, frame lines can be marked on the half model. Two other sets of lines are of interest: the water lines and the longitudinals.

By marking the outside mold with the horizontal center line and water lines beyond those shown in the body plan, we can transfer the information to the half model. Center line is correct relative to the WL's shown (Fig. 56) and is square to the back board. Setting this mold over the half model and adjusting it to suit the water-line marks on the back board, we can spot the center line along the length of the model. A thin (1/16 in.), wide (1/2 in.) batten can then be used to draw the center line on the model. Pins can be used to hold the batten in position. Of course, other lines parallel to the center line can be drawn on the model by the same means.

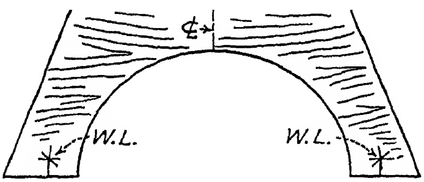

Fig. 56.

The longitudinals having been located on the body plan, we can work from that to the model. The girths from the vertical center line to the longitudinals can be measured on the body plan by use of a flexible scale, and spots established on the model. Battens through the spots will give the run of the longitudinals. All the longitudinals having been established on the model, we need only locate correctly the decks, bulkheads, cockpit openings, wing root, and similar structures before starting to arrange the shell plating. Shell plating is to a certain extent something

that can be adjusted to suit the other structures marked on the model.

Shell plating in the case of a hull bottom runs fore and aft. In the case of the upper structure of a hull, also, it is usual to run it fore and aft. In fuselages, shell plating may run fore and aft or athwartships. In wings and other surfaces the length of the plating runs with the long dimension of the surface. In ship construction, strakes of shell plating run fore and aft. Airplanes are increasing in size, which requires some system of marking and designating plates. Strakes of plating can be designated *A*, *B*, *C*, *D*, etc., starting at the keel or at the bottom underneath strake. We have plates starboard and port. Plates can then be numbered fore toward aft, or vice versa. The kind of joint, butt or lap, is another mark required for clear understanding.

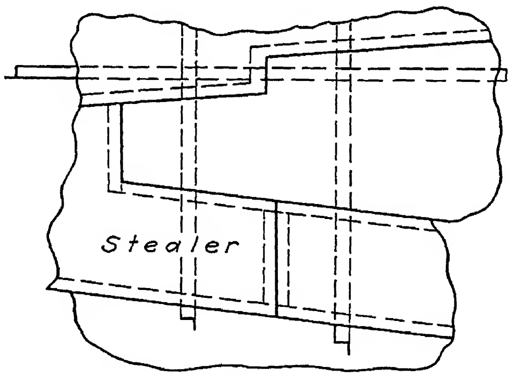

FIG. 57.

It is usual to start the shell arrangement near the deepest and widest section of the hull or fuselage. Sizes of raw materials available and the capacity of the airplane manufacturer's machinery are some of the limitations on the shell arrangement. The curvature of the hull or fuselage and the location of frames, longitudinals, and other structures also influence the arrangement. Other things being equal, it is best to run the plates as long as possible. Sheets tapering so that edges run with the longitudinals give a good appearance, but with the more general use of flush plating there may be good reasons for maintaining uniform widths.

By working from the greatest section, we can line in the plating directly on the half model. In establishing the plate edges, it is

best not to force the batten too much so that we can obtain plates whose edges will be as near straight as possible when developed. As we come near the ends of the hull or fuselage, plates become unnecessarily narrow. To drop strakes, one strake takes the place of two at a butt, or a stealer is introduced.

The stealer method is necessary in certain constructions, owing to interferences were the normal method followed. In the upper part of Fig. 57 a plate edge has been carried across a longitudinal square to the longitudinal to prevent a difficult riveting situation.

Before we can accept the shell-plating arrangement worked out on the model, we must fair the plate edges to full scale.

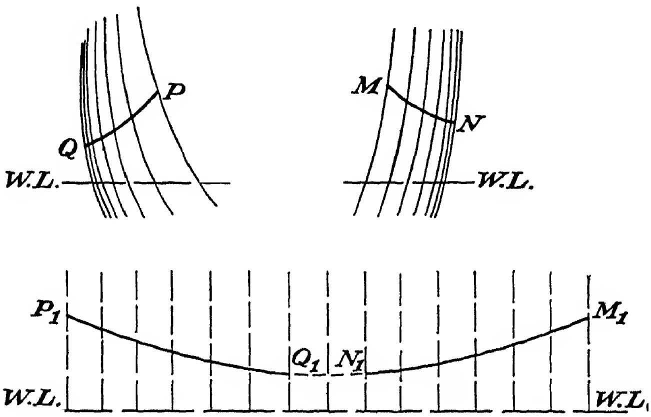

Fig. 58.

With respect to a large airplane the model may be too small to be truly representative, and errors in the fairing, if done on the model, will be the result. By using a flexible scale, we can measure the girths on the model from a water line or from the center line at stations concerned. These girths are transferred to the body plan as points. The points are faired in becoming the plate sight edges. If these sight edges are fair, the plate edges will be fair. Where the stations are so close together in the body plan that intersections are not clear, we can fair by a form of contraction.

In Fig. 58, MN is the sight edge in the forebody, and PQ is the sight edge in the afterbody. Where stations are numerous, we cannot fair sight edges readily in the body plan. On a con-

tracted profile, we can establish stations and a water line. MN and PQ are projected on the contracted profile. Q_1N_1 is then faired on this profile to connect with P_1Q_1 and M_1N_1. Projecting Q_1N_1 to the body plan will give the desired curve for the sight edge being handled.

The plate edges having been faired, they can be lifted back to the model for corrections that may be necessary. They are then marked in permanently on the model. The half model is then marked to show any differences between the port and starboard arrangements. Different colors for marking on the half model the frames, longitudinals, shell plating, etc., is a useful detail.

Openings, doors, and other items that have an effect on the shell and that are to be built into the hull or fuselage are marked on the model in some distinctive manner.

The model, having been permanently marked, becomes the basis for the shell-expansion drawing. By measuring with a flexible scale, we can take off the plate lengths from the model. The plate widths can be taken from the model or from the body plan. In any case, allowances are made for joints where necessary. On a plan where the stations are laid off to scale square to the horizontal center line, plates are drawn into an expanded view from the measurements given by the model and the body plan. Plate edges are faired as may be required. The result is a drawing of the expanded shell that is substantially a development of the half model. Butts, laps, and other connections are shown. Sheet numbers and sheet thicknesses are indicated.

The half model and the shell expansion are valuable in planning manufacture and construction, in that they give material sizes and information on jigs, fixtures, and forms required for working the plating.

Mocking Up. As has been mentioned previously, the most important tool of the loftsman while he is engaged in laying out an airplane is accuracy. First, last, and always, he must enforce the standards of accuracy. Were he to neglect this, troubles in the shops could develop and multiply so rapidly that large pieces of work would be utterly worthless. This brings us to the point that the loftsman's profession exists for the main purpose of facilitating the construction of the craft in a way that is impracticable otherwise.

First, the loftsman makes it possible to simplify the manufacture of the parts that are to make up the structure. Next, he improves the form of the airplane by applying known principles to full-scale lines. But, more important than these, the loftsman's work permits the manufacture and construction to proceed without resorting to a "cut-and-try" procedure. Were it not for the laying out of the airplane structure on the mold-loft floor, the airplane mechanic would have to make pieces oversize and fit them into place by trimming and fitting. He would have to lift templets from the work. His endeavors would be slow and tedious. All this is eliminated when we can manufacture parts directly from a templet made in the loft, with good assurance that the part will go into position and that no "trial-and-error" methods are needed.

The loftsman must bear in mind that the shape, form, and contour of all surfaces must be fair. If he cannot determine that such is the case from his lines and models, he may have to resort to mocking up the volume concerned. He must see that room exists for the structure, the equipment, and other installations which go together to make the airplane. His lines and projections serve to help this picture; but where intricacies are involved, visualization may demand a three-dimensional representation. The loftsman must ensure that parts built to his lines and templets will assemble to make the airplane a good example of workmanship. To accomplish these things, the mold-loft crew work on the basis that they must "see" the part and the whole as finished products. Where the lines, models, molds, forms, etc., will not give a true picture, it is essential that other methods are followed. Not infrequently, it is a case of bringing the matter to full scale. In other instances, full scale in three dimensions is the only solution.

A surface that has curvature in two directions cannot be developed. Most hull, fuselage, and wing surfaces fall in this classification. Generally, the matter can be settled through the use of the loft lines, but truly representative examples are required where the difficulties are likely to lead to unwarranted errors. In such instances, it is reasonable to resort to mocking up the structure. As the name implies, a *mock-up* is a full-scale model made by using a wood skeleton type of construction. The mock-up is full scale in three dimensions, supported from a floor by

"horses." A complete airplane may be mocked up, or the mock-up may be of certain sections only.

A mock-up serves to give information (1) on the shape as it will be, (2) on the dimensions as they will be, (3) on the working and clearances of a movable part, and (4) on the relative positioning of installations. For example, if we mock up the bow portion of a hull, we can study and adjust the arrangement of equipment, such as the ground tackle, which needs special attention to ensure satisfactory stowage and operation. In addition, we can lift templets directly from the mock-up for bumper, bow plating, chine angle, and other parts of the structure in the portion represented.

In building a transport airplane a mock-up of the cabin space is essential to indicate the arrangement expected. By making a mock entrance with doors, decks, ladders, and handgrips, the designers can get a good idea as to the practical features involved. By making a mock-up of the cabin with seats, berths, ports, aisles, and baggage stowage, adjustments leading to correct arrangements are possible. In all mocking up of such a nature, it is customary to make the structure representative insofar as space is concerned and doors, seats, and other moving features movable and adjustable throughout the range of action. Ports and windows are indicated to give a fair idea of the visibility angles that will prevail in the airplane.

Another useful form of mock-up is one that will clarify a maintenance problem. Where the engine compartment is likely to be overcrowded, a mock-up showing pipe lines, electrical leads, control leads, tanks, and accessories will show the degree of difficulty involved in maintenance. It will also permit improvements in arrangements without waiting for the completed airplane to suggest ideas along that line.

Because of the limitations to airplane size, the inside of the wing is being used more and more for installations of various kinds. These installations are being entered in a volume that is cut up extensively by the normal structure. The consequence has been that space inside a wing is at a premium. Clearances are small, access is difficult, and interferences are numerous. To run surface control leads, fuel lines, deicer lines, and gun controls correctly and to arrange beams and ribs to suit, we are confronted with problems most easily solved by mocking up the

whole arrangement. Besides giving data on arrangement and space, the mock-up can be used to give data on the lengths and shape of control leads, pipe lines, cables, and other mechanisms. The advance data secured in this way is of value, for it is not necessary to wait to take templets from the work. As a matter of fact, it may be best to arrange the mock-up in such a way that it can be used for that very purpose when it has completed its other functions.

In mocking up a structure so as to obtain templets of the parts concerned, horses can be framed to represent the inside or the outside surface form (see Fig. 59). A fuselage mock-up would have framed molds inside; *i.e.*, a templet for a shell plate would be lifted from the outside. If we were to mock up for a bottom shell plate near the bow where the curvature is strong, it would be best to cut the horses to fit the outside of the frame lines. A series of horses set up at the proper stations square to the floor and fixed accurately with reference to the center line or some other reference mark will give a mock-up from which the shell-plate templet can be lifted directly.

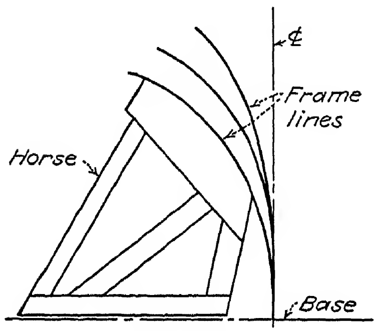

FIG. 59.

It is not necessary that the mock-up shall retain a position in space corresponding to the finished airplane. Where the plate to be lifted is vertical in the finished craft, it is best to establish new reference lines so that the tops of the horses will come more or less parallel with the floor. We can build such a mock-up with little trouble in squaring and bracing; and, in addition, templets are lifted with more facility than would be the case otherwise.

The student must distinguish between a mock-up which is essentially a means for lifting templets and a skeleton form which is used to jig the forming of a shell plate. Sometimes the data from the mock-up become the basis for the skeleton form, but it is impracticable to combine the two. The mock-up is light, easily shaped, and without permanency, whereas the form is strong, rigid, and capable of taking manufacturing blows. We shall go into the matter of forms more extensively later. (Chap. V, Templets, Jigs, Fixtures, and Forms.)

Before leaving this subject, it might be well to mention that matters worked out in the mock-up stage may influence not only the experimental airplane under immediate construction but hundreds of others that may follow. Consequently, the loftsman must have regard for quantity production even though his considerations and deliberations seem to be directed at a single craft. There may be no recourse to going back over the work once the program has commenced, and therefore care and attention to details are fully warranted.

CHAPTER V

TEMPLETS, JIGS, FIXTURES, AND FORMS

Lines and Surfaces. The loftsman's output is templets. He takes the lines, curves, surfaces, and space of structural drawings and develops them into templets. These templets serve as the medium in the shops for accurate full-scale interpretations of the structural drawings. Although the templet is essentially a two-dimensional interpretation of the three-dimensional structure, it is produced in such a way and in such combinations as to make manufacturing easier and more economical.

Thinking in three dimensions is an art. We get so used to working on paper that we lose sight of the fact that most things have thickness as well as length and breadth. There are many ways of overcoming this difficulty in industry, but we do not find it efficacious to rely upon anyone excepting those whose business takes them into three dimensions regularly. For this reason, we are fortunate in aircraft when we can demand that the problems of lines and surfaces logically fall to the lot of the loftsmen.

Let us briefly review the subject of lines. A straight line can be explained by giving its length. A line curved in only one plane requires a templet to show its shape and a length to show the size of the raw stock. This length is a development of the shape. Mathematicians like to regard a curve as exhibiting the plot of an equation that obeys some sort of law. Because the number of curves in space is so great that it is practically impossible to recognize one as having a known identity, the loftsman cannot follow the mathematical procedure. Enough if we state that a curve can be regarded as the envelope of its tangents. At any point P on a curve, we can draw a tangent. The line perpendicular to the tangent at P is the normal. If we regard only a small part of the curve at P, an arc of a circle should coincide with the curve. This is the circle of curvature at P. The radius of this circle will coincide with the normal. Therefore, as an approximation, the curve at P may be replaced by the tangent or by the circle of curvature.

A twisted curve leads into more than one plane. Any small part of such a curve can be considered as falling in an osculating plane. Tangent, normal, and circle of curvature fall in this osculating plane. Because we need a third reference axis, we can use the binormal which is perpendicular to the tangent and the normal. As may be necessary, we can portray the curve, using tangent, normal, and binormal as the axes.

One of the best ways to express a curve is by the length of the arc and by the angle between the tangents at its extremities.

A large number of curves special in character have been developed through the use of equations. They are mathematical curves fixed in form and well defined. The simpler of these, such as the cardioid, circle, catenary, ellipse, cycloid, helix, spiral, harmonic, hyperbola, and parabola, may be encountered frequently. Unusual mathematical curves may make an appearance in aircraft forms when we have learned more about contours and aerodynamic reactions than we now know. When they do occur, the loftsman may have gained by plotting against coordinates if this becomes possible.

As with lines, surfaces move from the simple to the complex. The plane surface is easily handled. Dimensions, areas, and other characteristics are readily expressed. Where a simple bend occurs and the surface continues in another plane, we still have a simple problem. If the bend occurs so as to throw the surface into a skew plane, true shape and size can be determined and expressed by rotating the reference planes as may be necessary.

But an airplane structure conforms to aerodynamic considerations which, in turn, depend entirely upon curves of varying contours. Where many planes are encountered but with the curvature in one direction, the development is largely a matter of unrolling. For cylinders, conical shapes, and other shapes such that a straightedge can be fitted to them, development follows straightforward simple rules.

When we approach surfaces having curvature in two directions, we enter a phase in which the loftsman needs his full skill to produce a near development that will serve the purpose. Not only must the loftsman make the flat plate templet needed for blanking, but he must provide the templets to show the final form of the part. All this requires diligence, accuracy, and a thorough knowledge of lines and surfaces in three dimensions.

Undoubtedly, there are better methods possible than those used by mold lofts to develop, lay off, and templet parts which wander freely in three dimensions; but, for good practical procedures, we must rely upon those methods proved in practice and which the loft has found to be completely satisfactory. The loft must regard its work not as an end in itself but in relation to the further handling of its products in the manufacturing shops.

Operations. Before we begin a detailed discussion of structural parts, we propose to describe some of the shop operations affected by the mold-loft layout. Practices in this respect may vary considerably in different manufacturing plants, but the results are substantially the same.

To make any piece or part, we must first know the size of the blank from which it is to be made. The blank may be cut, routed, sheared, sawed, or blanked out in a press. To do this the loft provides a suitable flat templet. If the part is a tube, bar, rod, or shape, length is the only dimension that matters. If the part comes from a sheet, the flat plate form is a matter of importance. Flat templets for the sides are needed if the thickness is to be blanked out, also. This may be the case in machined fittings.

Bending the part along some straight line to some angle with the face requires that the location of the line and the angle of bend shall be known. Such bending may be produced by rolling and drawing where strips are to be formed. The rolls and drawing dies are ordinarily standardized. Straight-line bends may be made with brakes, presses, and flanging machines and by the use of forming blocks. Where the flanged side makes a faying surface with some other part, the angle of bevel requires a bevel stick or a suitable templet showing the bevel angle.

Flanging along a curved line, as in making a frame, requires data as to the flanging line and the bevel angles. Ordinarily, there is only one angle of bevel. In certain parts the bevel angle may change continuously from a maximum to a minimum. Presses and flanging machines are commonly used for producing the bending along a curve. Hand forming is effected by using suitable forming blocks. Hand forming is suitable where the number of parts to be flanged is limited to a few and where the part is complicated to shape otherwise.

Rolling edges, beading, corrugating, and similar operations are special forms of flanging. Direction and form give the essential information for these processes.

Cylindrical, conical, and similar shapes are produced by bending rolls. Some parts of such shapes may be made by spinning on a form. Templets giving diameters at various stations are complete for simple cylindrical and conical shapes.

Spinning is an effective method for producing a part that has circular sections with a varying diameter. Certain engine cowls are made thus, provided that the draw is not too deep and diameter is within the material size. Sometimes a spinning can be re-formed by hammering to produce shapes having oval sections. The templets needed are those showing the formed contour along various radii.

Many airplane parts have surfaces with complicated curvatures. Working the material so as to produce the desired shape entails a wide variety of special machinery or the use of standardized machinery with specially skilled mechanics. The automotive industry accomplishes results through the use of heavy presses, but the small quantity of airplanes and the absence of standardized forms in airplanes do not warrant the cost involved. It can be said, nevertheless, that methods suitable to the number of repetitive operations normal to the industry are in general use. Drop hammers with low-cost dies, mechanical presses, hydraulic presses, stretching presses, and like equipment are in general use for forming. In some instances, bending rolls are adapted to meet the requirements of complicated shaping. Most of the machinery mentioned is standardized insofar as the method of applying power to the material is concerned. The form and shape are produced by suitable dies and tools which are specially made for a given part. Infrequently, dies can be assembled so as to produce more than one part, but the complication involved cannot be regarded as warranted.

In order to make a die or a special tool for forming a part, there are needed templets or detailed drawings to show the size and form of the die or tool concerned. It is usual to make the die, try it out, check the part made, and then depend on the die to produce like parts. If there were any occasion to doubt the ability to produce exactly similar parts, templets could be used as a kind of gauging unit.

Sometimes it is unreasonable and impractical to go to the trouble of making dies or special apparatus to press out the part. On those occasions, hand forming may be the superior method. Hand forming ordinarily requires the use of a skeleton form or a

solid form. The form, of course, is made to the true shape of the finished part. This requires a complete series of templets for the form construction. And, in addition, it is prudent to have the finished form checked by the loft prior to its being put to use. It might be better yet to have the form built by the pattern shop connected with the mold loft.

There is still another class of parts that require special operations for their manufacture—long-shaped bars, for instance, that need bending, twisting, and flanging. For example, some longitudinals require peculiar working to make them fay properly with the adjacent structure. Sometimes it is necessary to make a complete form in which they can be tried and gauged to ensure that they will fit properly when they reach the assembly stage. Where quantity warrants it, special machinery and jigs are used. In either case the templets are carefully made, with complete directions indicated, so that too much cutting and trying do not occur.

Before proceeding, it might be well to mention that much of the credit for success in manufacturing structural parts rests with the loftsman and his templets, but the manufacturing-shop mechanics can mar that credit and that success if the making of the part is not accomplished with care and judgment. All the templets possible will not ensure correct fit, although they will facilitate the making of a part that ought to fit.

Drilling and Punching. After a part has been formed to the desired shape, it is necessary that it shall be arranged for fastening to its adjoining parts. Spot welding, riveting, and bolting are the three methods with which we are concerned here. These processes involve a degree of accuracy that may or may not be available in the manufacturing shops. In any case, variations in the relative order of operations permit procedures that are satisfactory on the whole.

If two parts are to be assembled to each other so as to form a unit which in turn must be assembled to another set of parts, we require that the unit fit properly. To an extent, this is made possible by the use of jigs. Drilling of the two parts can be accomplished in three different orders. If done with the two parts in a secure jig that holds them in the final true relationship, they will fit together very nicely. After drilling, they are separated for removal of burrs, cleaned, and reassembled. Riveting or bolting

is then in order. If we drill one piece from a layout before it goes into the jib, that piece becomes the drill jib for the other part. Separations, cleaning, assembly, and riveting proceed as before. According to the third order, we drill both pieces from a layout before they enter the jig. They enter the jig for the first time as finished pieces and are riveted in place. This third method requires accuracy, for misalignment of rivet holes requires reaming which is almost as difficult as though no drilling had been done in the first place.

It is desirable to have parts finish-drilled after the parts are formed if that is at all possible. This is in the interests of efficiency and economy. The only danger is the misalignment of holes. And because we have a wide variety of parts in an airplane, it may be advantageous from the manufacturing shop's viewpoint to use the third order wherever possible, reserving the second and first orders for parts that have shapes which do not incur unusual difficulties.

In laying off a templet to become a drill jig, errors occur through variation in edge distance, variations in end distance (at the end of a row), and because layout is not uniform. The first two difficulties can be handled by laying off drill templets for adjacent parts and at the same time using a single hole (or a few holes) as the initial guide. The last-named difficulty can be overcome by using standard rivet-spacing jigs for laying out the templet or by using multiple punches and drills set to standard spacings. These multiple drills use a drilled hole as the guide. "Try fits" of pieces completely drilled are regarded as a reasonable precaution. If, for some reason, try fits show that the possibilities of errors are too great, the shop can fall back on partial drilling in place as the solution.

In spot welding, it is not quite so important to line up the "spots" as is the case with drilled holes; for even where spot welding is the process being used, some drilling and riveting come into the picture for temporary assembly. Edge distance of spots and distortion due to welding must be under control.

Dimpling of parts to produce countersunk conditions in riveting is similar in operation to drilling. Dimpling should be done if possible before assembly, for reasons of convenience. However, portable tools are available to handle dimpling of parts when the parts are "bolted up."

If "stopwaters" are used, it will be necessary to drill before the stopwaters are put into place. This can be done conveniently after the parts have been disassembled for cleaning, provided that parts are not finish-drilled from drill jigs. If they are, we can assemble parts and stopwaters as a finished operation when the parts enter the assembly jigs.

In all this, there is one important element for the loftsman. In making lay-offs of parts, juxtaposition pieces should be considered at the same time and the templets tested against each other. This trial fit is a worth-while check. It applies in cases where we have openings fitted with doors, where equipment brackets are installed, and where major assemblies meet with other major assemblies. Many devices are used to allow large tolerances, but the loftsman must rely upon his accuracy to bring the whole into being, even though he may have some "come-and-go."

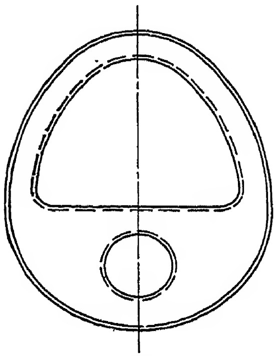

FIG. 60.

Frames, Bulkheads, and Ribs. Although there are many differences among these parts, they all serve the purpose of giving and supporting a transverse contour. In this discussion, therefore, we shall handle them as a group. Owing to the limits of our task, only typical examples will be presented. The student will obtain the major part of his education through experience after he has gained a footing in the principles involved. Of course, our task is to present a foundation only.

The body lines are the clue to the templets for a frame or bulkhead. The outside dimensions come directly from the lines at the frame concerned. In this respect, hull and fuselage frames are alike. It is to be noted (Fig. 60) that the frame flange is beveled, and this bevel may or may not be uniform around the edge. The bevels of frames vary along the length of the hull or fuselage concerned. Customarily, some form of bevel stick is used to obtain the angle of bevel. If we know the frame spacing, we can measure the transverse distance between projected frames in the body lines. This gives us two sides of a right triangle in which case the angles are given by $\Theta = \tan^{-1}(a/b)$, where a equals transverse

distance and b equals frame spacing. For any frame spacing a bevel stick can be made so that if it is laid on the body plan the distance from frame line to frame line gives the bevel in degrees.

In Fig. 61 the use of the bevel stick is portrayed. Bevel sticks are available in the loft for various frame spacings. If not, it is a

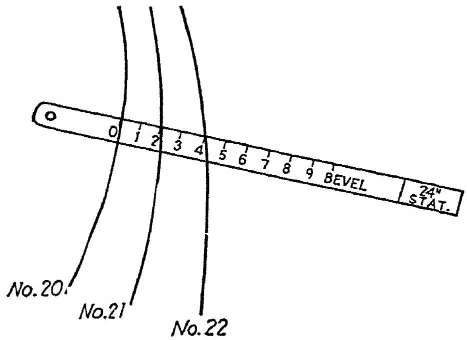

FIG. 61.

simple calculation to make by the use of the right-triangle method. Bevel boards or sticks may be more convenient if made of transparent plastic.

We come now to the lay-off of the rivet holes. As far as brackets and other attachments that are made to the frame itself are concerned, there is little difficulty involved. Lay-offs of these attachments are made full scale on the templet under construction. Rivet holes are spotted as may be dictated by the layout, care being taken to record the layout on the attachment templets to agree with the frame templet. Difficulty will be encountered in the layout of the rivet holes necessary for shell-plating attachments. At the time that the shell plate is laid out, rivet holes are fixed in the plate and in the frame to agree with each other.

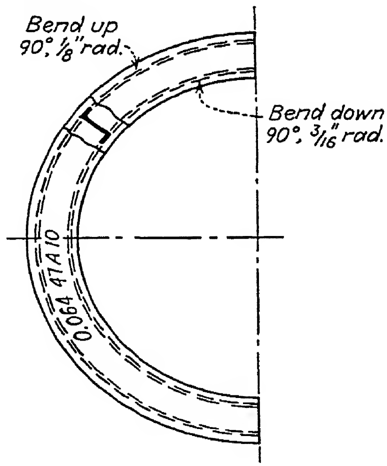

FIG. 62.

So far, we have assumed that the material used for the frame templet has been painted metal. Of course, there is no reason why the frame templet could not have been wood, transparent

plastic, or any of the other materials ordinarily used for templet layout. Figure 62 shows a typical frame templet.

If the frame is not perpendicular to the base line or to the horizontal center line, we have the kind of frame termed *cant frame* by the shipbuilders. Such frames do not occur frequently in aircraft construction; but because the principles concerned may have some bearing on topics treated later, we shall go into the matter briefly. Ordinarily, such a problem involves the use of three views, together with the needed auxiliary views to show the true shape or expansion. The data on the three views can be obtained from the body, profile, and half-breadth plans after which rotation about some axis will produce a view that gives true dimensions.

The profile view will give the angle that the frame makes with the base line. It will also give the angle through which the frame

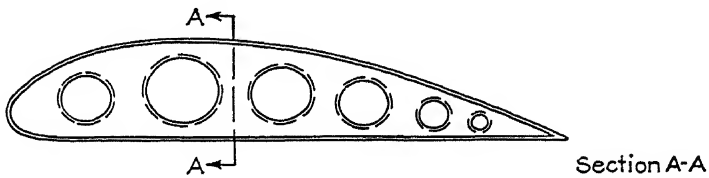

FIG. 63.

must be rotated to place it in the desired plane. The height is given by the profile and the width by the half breadth. From these dimensions, we can determine the body view. But because the frame does not fall into a station plane, the body view is not true. As was explained Chap. II under Descriptive Geometry, we can develop an auxiliary view which is perpendicular to the frame and which gives data for the construction of the templet. By plotting both the heel and the toe of the frame flange in all the views, we can see the form taken by the bevel. The amount of the bevel in distance is the length shown in the auxiliary view between the heel and the toe of the frame angle.

Wherever practical to do so, bevels of frame angles are made so as to be open; *i.e.*, the angle should increase from a right angle rather than decrease. This facilitates construction, particularly the riveting where backing-up tools have to fit close to the bosom of the angle.

As has been said, a wing rib (see Fig. 63) is in the nature of a frame. The profile gives the outer contour of the rib and the plan

view the relative location on the wing beam. Because of the way ribs are made for current types of aircraft, we may be concerned with many pieces. The interceptions are produced by multiple or single beams. If the wing covering has strengthening in the spanwise direction, the rib is constructed to suit.

Wings may have tapering leading and trailing edges. Ribs are set in a fore-and-aft plane following the chord line. Also, they are as nearly perpendicular to the outer skin as it is practicable to make them. The consequence of this is that the loftsman must be careful to keep his reference planes and lines on record to get the true view. The templet should embody all the information in this respect.

The wing lines as laid off in the mold loft give the limiting dimensions. For a particular rib, these lines are transferred to the templet by means of a pantograph, by tracing, or by photographic reproduction. The structural drawing for the wing gives the arrangement of parts and the materials to be used. For each part the loftsman prepares a blanking templet, a form templet, and a drill templet. Of course, one templet may serve all three purposes. A wing rib is in a single plane which simplifies the matter. This feature also makes it possible to produce an assembly board for the rib.

The blanking templet, as for the cap strip of a rib, gives the developed length and the shear of the ends. If there are other cutouts, these can be included in the blanking templet.

The form to which a part is to be bent is given by the form templet. This comes directly from the rib lay-off which, in turn, has come from the lines; there is thus no occasion for error in the shape of the article produced. Information on joggles, bends, bevels, etc., is embodied in the form templet so that the part resulting will assemble without further forming operations.

The drilling templet could well become the drill jig. This is one of the advantages that exist where the loft reaches into jig, tool, and form manufacture. Templets in some cases can be used for jigs and forms, and an additional step is thus eliminated. This advantage is enhanced further where photographic reproduction permits the making of several prints of the layout. These prints being on metal, plastic, wood, or other suitable templet material can be cut up and used to fit a number of purposes connected with the making of parts and their assembly.

In assembling ribs, it is quite common to use an essembly board. If the rib is laid out on a board, blocks for supporting the parts are readily fitted to suit that layout. It is to be noted that a print made on wood from the master layout becomes a convenient basis for an assembly board. Because the exact location of every piece, together with the location of the assembly rivets, is determined from the master by a direct photograph, errors tend to be eliminated.

The rib, or any frame for that matter, should have clips or pieces that permit its assembly to the beams secured in position. In making templets the loftsman must facilitate the sub-assembly and assembly by diagnosing the order of assembly. Not all combinations will be of like convenience; in order that the best may be available to the shop mechanics, the loftsman will find it necessary to study the variations involved and select groupings that will be effective and efficient.

While we are on this subject of assembly it might be mentioned that layouts give an excellent clue as to the possibilities and the practicabilities of assembly. Fitting of parts together to form a whole is only a scheme of things. The loftsman must watch to see that the impossible is not planned for. He does this by studying the lay-off as he proceeds. Further, where nooks and crannies are so small that it is well-nigh impossible to get a holding-on tool into position for riveting, it is best to alter the construction in the layout stage. Laying off the rivet holes has a bearing on the outcome. Jammed rivets are worse than none at all. Make the lay-off orderly, and see that room will exist to permit the easy construction that is desired.

Again it might be mentioned that accuracy is essential. The final form of the hull, fuselage, and wings depends very much on the frames and ribs. Shell plating, being thin, will follow the frames. It can be seen, then, that, if the lines are to be fair in the finished airplane, accuracy with respect to the frames is as important as in all aspects of airplane lofting. Frames and longitudinals form the skeleton of the structure; and, to a great extent, the results of the finished hull or fuselage are controlled by this skeleton. It is clear that errors in the basic setup may throw the whole structure into difficulties. Where clearances cannot be definitely established from the lay-off, it is best to allow the metal to remain for the exact cut to be made on the assembly.

Longitudinals and Beams. In fuselages, floats, and hulls, we use longitudinal stiffeners. These longitudinals may be extended to become fore-and-aft bulkheads. In surfaces, including wings, the beams serve to give the structure character in the spanwise direction. Stiffeners may be used in surfaces to strengthen the structure provided by the beams. Except for some similarities in the layout work, longitudinals and beams are not alike. They are discussed together because the lay-off of beams and longitudinals involves like measures.

Longitudinal stringers in fuselages and hulls are generally shallow except where concentration of strength demands a deep structure. In hull bottoms, longitudinals may take deep sections. Stringers may be intercostal or continuous. It is customary for some part of the longitudinal to be continuous even though other parts are intercostal. Owing to the fact that longitudinal stringers follow a hull curvature along its length, twist is quite likely to occur.

Longitudinal bulkheads may be incorporated for sectioning the hull or fuselage or for strength considerations. These may be partial or complete, watertight or non-watertight. Twist in bulkheads is not likely.

Wing beams may be single, double, or multiple. They extend through the depth of the wing. Depending somewhat on the general shape of the wing, beams may or may not have twist. Twist complicates layout and manufacture considerably. It brings curvature which requires many planes to show true views which, in turn, necessitates special care and attention.

To handle the lay-off of longitudinals, it is necessary to follow the lines at the mold on the outside and the lines at a false mold on the inside. In other words, we must establish the outside and inside edges and erect the longitudinal between these edges. This requires some fairing to make the longitudinal follow the desired pattern.

First, transfer the part of the body lines concerned to the lay-off. On these lines, we can establish the outside edge of the longitudinal. At this point, it might be well to mention that checking battens, used extensively in shipbuilding, are not used in aircraft construction as much as might be advisable. A longitudinal lifting batten for checking the form of the hull or fuselage can easily be made from the lines just transferred. It will carry mark-

ings to show the height of the outside edge of the longitudinal above the base line for each frame. Allowances must be made for shell thickness if that is involved. Figure 64 shows transferred body lines and the base line. If the sight edges of the shell plating can be applied, they are to be drawn in to avoid interferences between seams and longitudinals. *AB* is the outer sight edge of the longitudinal intersecting frame lines 50, 52, 54, 56, and 58. This line can be faired by plotting it on the half breadth or on the profile. At each frame in the body, draw *AD*, *EF*, *BC*, etc., perpendicular to the frame lines. If the longitudinal is uniform in depth, $AD = EF = BC$. The fairness of *DFC* can be tested

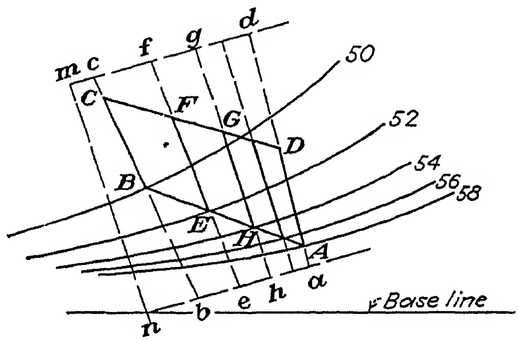

FIG. 64.

by plots in the half breadth or the profile. Other longitudinals can be shown in the same manner.

The longitudinal can be expanded by working on a templet or by making a mock-up. Let us consider the former method (Fig. 64). Draw *mn* parallel to *GH* the middle frame. Erect perpendiculars *na* and *md*. Produce *AD*, *CB*, *EF*, and *GH* to intersect *na* and *md*. On an expansion templet (Fig. 65), lay down *nn′* with body stations perpendicular thereto. Use full scale in each case. Lay off *mm′* parallel to *nn′* and at a distance *nm* above *nn′*. Then, lift *Bb*, *Ee*, *Hh*, and *Aa* from the body view (Fig. 64) and transfer them to the templet (Fig. 65). This gives curve I. Lift *Cc*, *Ff*, *Gg*, and *Dd*, and transfer them to the templet. This gives curve II. Lay a flexible batten on curve I, marking the frame positions. Now hold batten at frame 54, and allow it to straighten along *nn′* which gives expansion of the frame positions. Using curve II for the upper edge, plot the expanded position of frames along *mm′*. Joining the frame positions at top and bottom, we now have

expanded frames. Now plot bB, eE, hH, and aA on the expanded frames from nn'; plot cC, fF, gG, and dD on the expanded frames from mm'. Fairing in the curves gives CD and AB on the templet which is the approximate development. If CB, FE, GH, and DA are parallel in the body plan, the development is true. Where they vary considerably from parallel, much twist exists in

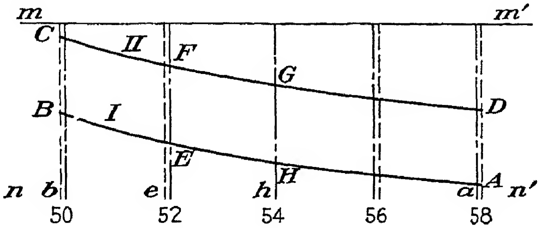

Fig. 65.

the longitudinal. Where considerable twist occurs, it may be advisable to resort to expanding the longitudinal by mocking up.

In Fig. 66 is a transferred body-line templet with longitudinal $ABCD$ intersecting frame-line sighting edges, AB and CD being as shown. From A, G, E, B, C, F, H, and D, drop perpendiculars to the water line MM'. Transfer the sight edge AB to a half-breadth view by squaring B, E, etc., out from the center line. For

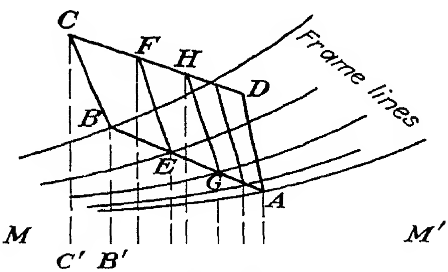

Fig. 66.

each station on the body view, make a templet of $CBB'C'$. Setting this templet on the half-breadth view on the station concerned, with B properly positioned, and perpendicular to the center line, we get a true view of the longitudinal edge BC. Do this for each station. The edges of the longitudinal will be shown by these templets. By making a templet from this mock-up, we shall get an expanded longitudinal, for the mock-up shows the true form. A permanent form may be needed for a longitudinal

with much twist. In that case the mock-up is assembled securely as each frame form is established.

Shell Plating. The plating on hulls, floats, fuselages, wing surfaces, and tail surfaces presents various degrees of complication. Variations from flat sheet to extensively formed sheets exist. It is only the formed sheet that requires the full technique of the loftsman. The principles and processes involved in laying off plating depend more on the final form than they do on the location of the plating on the airplane. For that reason, the examples given must be generally applied.

The shell plating on hulls and floats is arranged with the long dimension fore and aft. The covering of a wing has the long dimension with the span. Fuselage plating, on the other hand, may be fore and aft or with the frames. The latter possibility is explained by the fact that the fuselage may be truly conical in shape. This permits the use of sheets with roll forming only if the long dimension is with the frames. It may be practical to use the flat sheet directly, provided the sheet is thin.

Ordinarily, shell plating is assembled to the structure without applying tension. There are instances where tension is called for to give a tightening effect. Although this tension is not great, the loftsman must allow for it, if it exists, in making his lay-off. Where the plating is heavy or extensively formed, stretching is unnecessary and complicating.

The half model and the expanded plating drawing give the loftsman data on plate location, approximate size, thickness of plate, laps, butts, seams, rivet spacing, openings, etc. Models and drawings will give a fair idea as to the extent of the forming involved. Laying out of hull plating may begin at the step, working fore and aft. Laying out fuselage plating begins at the fire wall. Laying out wing plating begins at the wing root.

Before discussing the laying off of shell plates, it is advisable to stress again the aspect with which the loftsman is concerned. Each plate must be developed or expanded for the blank. The blank must be formed to the required curvature; and, if necessary, joggling or preparing edges is in order. At this stage, we have a plate that will fit into place but that has not been punched or drilled for fastenings. In any case, some pilot holes are essential for holding the plate in place. Not to go into the details of drilling, we must drill the sheet from a templet or from work.

Omitting, for the time, the jigs and forms needed, the loftsman must provide a blanking templet of the plate and the essential information on curvature. With some reference plane, curvature can be given by templets made to follow the frame lines. These can be inside or outside templets. If a further check on curvature is required, use a templet formed to meet a water line. The templets made to show the curvature can be used to make the skeleton or solid forms needed in manufacture.

Because the problem of expanding the shell plating is special in character, we shall devote considerable space to detailed explanation of the process. Of course, it must be understood that the principles are applicable to many parts other than the shell.

Where the plates are straight and flat, the blanking templet may be taken directly from the body plan. The frame locations are laid out on the templet. In order to establish the sight edges, battens are bent to the form at the stations concerned on the body plan. Lengths are marked and transferred to the templet. The lengths having been marked at the frames or stations on the templet, the plate size is established. It is thus seen that the process is simple where no curves are in the surface.

Many methods have been invented for developing shell plating having curvature. All are the result of ingenuity with varying degrees of accuracy. Each method is based on the principles of geometry, the fundamentals of which have been given previously. Geometry has taught us the simplicity of expanding or developing cylinders and cones. Unfortunately, where double curvature exists in a plate, it is truly undevelopable. Nevertheless, the loftsman must make a close approximation to the development of a sheet to accomplish his "reason for being." And he must do this from the mold loft lines of the airplane concerned to gain the advantages that lofting presents. Several methods of developing shell plating will be described so that the student will be aware of the possible variations. All are the results of the experience of practical ship loftsmen.

The *straight-line method* is rapid and easy and meets most requirements for plates that have little twist and small curvature. It derives its accuracy from close frame spacing and narrow width of plate. Short distances are regarded as straight lines in the actual plate, as will become evident from the following description.

In the body plan, we have a plate with upper and lower edges, and with butts, as shown in Fig. 67. We select a midway frame (No. 134). About halfway between upper and lower edges, locate point A and strike in straight line ZY through A and perpendicular to the frame line.

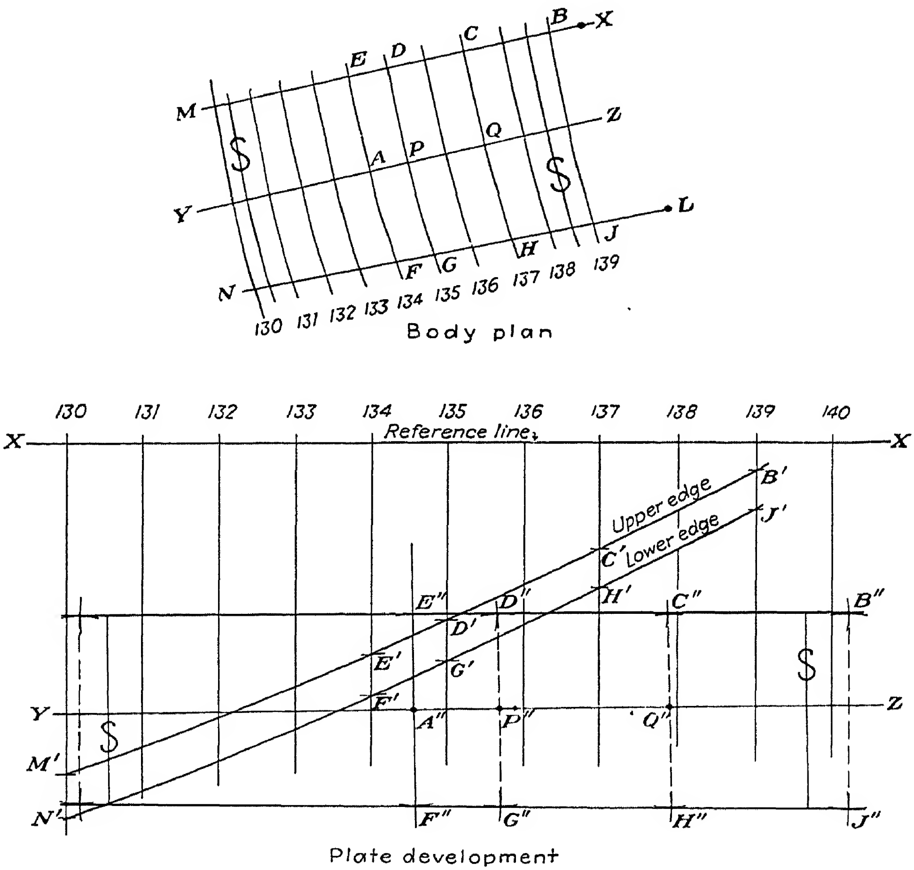

FIG. 67.

With a batten along the upper edge, lay off XB, XC, XD, XE, etc. X is any free point. It is to be noted that XM is in a diagonal plane and that these distances laid off on the batten represent distances from a fore-and-aft line through X. With a batten along the lower edge, lay off LJ, LH, etc. On a half-breadth or profile view of the frames, lay off these distances from a straight reference line as shown. This gives a view of the upper and lower

plate edges from a fore-and-aft plane. We get $B'M'$ and $J'N'$ as the edges.

On a clear part of the loft floor, lay down YZ as a straight line. At some convenient point, establish A'', and draw $A''E''$ normal to YZ. Lay off $A''E''$ equal to AE and $A''F''$ equal to AF. From E'', strike arc $E''D''$ equal to $E'D'$; from F'', strike arc $F''G''$ equal to $F'G'$. A tangent to arcs at D'' and G'' establishes P''. With P'', strike arcs so that $P''D''$ equals PD, and $P''G''$ equals PG. By working on in this manner the plate becomes evident as the faired lines go through the established points.

A method of checking is to bend a batten around the frame in the body plan to obtain the girth and to try it on the plate development.

This straight-line method of expansion is based on the assumption that plates are straight between frames and for about one-half the plate width. For a higher degree of accuracy, increase the station lines and the straight construction lines (YZ).

The *squaring method* of plate expansion has the feature of being rapid and easily applied. As in the straight-line method, we scribe the plate edges on the body plan. As shown in Fig. 68, AF represents the top edge and GL the lower edge of a plate. Stations are indicated. The butts are on a half-station plane perpendicular to the center line.

As previously, we lay off distances AB, AC, AD, etc., along the upper edge from a point A, all scribed on a batten. To visualize this, assume A is a line parallel to the center line. These distances will give the curve of the plate edge in a diagonal plane. On a plan with stations spaced full scale and parallel, lay off $A'F' = AF$, $A'E' = AE$, etc., all from the reference line. This gives the plate upper edge. Do likewise to obtain the contour of the lower edge.

Establish $F''G''$ on the loft floor. Draw $F''M''$ normal to $F''G''$. On the body plan, draw FM perpendicular to station 23, EN perpendicular to station 22, etc. Also, draw GP perpendicular to station 23, HQ perpendicular to station 22, etc. On the plate development, scribe $F''M''$ equal to $F'E'$ and $G''P''$ equal to $G'H'$. $F''M''$ and $G''P''$ are perpendicular to $F''G''$. Make $M''E''$ equal to ME and $P''H''$ equal to PH. Now, working from E'' and H'', repeat the operations with the corresponding dimensions given. Repeating the squaring will give point F'', E'', D'', G'', H

etc. Fair lines through these points will give the plate contour as expanded.

A modification of this squaring method is used by some loftsmen for convenience. Instead of drawing *FM*, *EN*, etc., normal

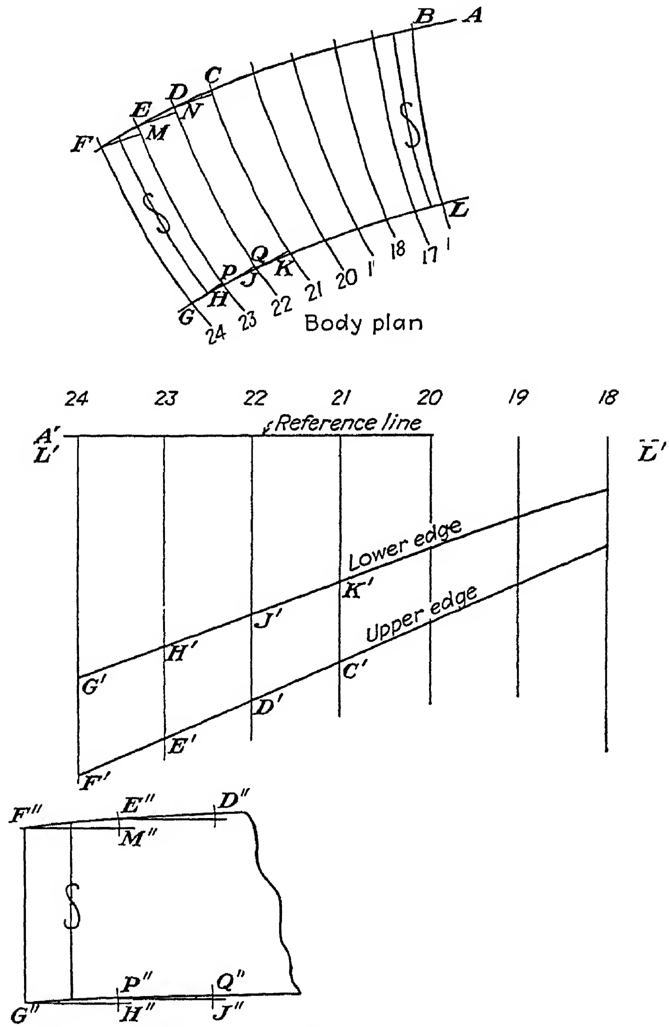

Fig. 68.

to the stations at these points, straight lines are drawn between *F* and *G*, *E* and *H*, etc.; and *FM*, *EN*, etc., are drawn perpendicular to these straight station lines. The results are substantially the same.

All methods of expanding plates depend on obtaining distances in the line lay-off that can be regarded as straight. These distances laid off straight in the correct direction give the approximate development that is sought. The more curved the sheet, the shorter the distances used and the more tedious the layout becomes. In certain cases the squaring methods of plate development do not give the desired degree of accuracy. In such instances the triangulation method, which we are about to describe, is preferred. This triangulation method is com-

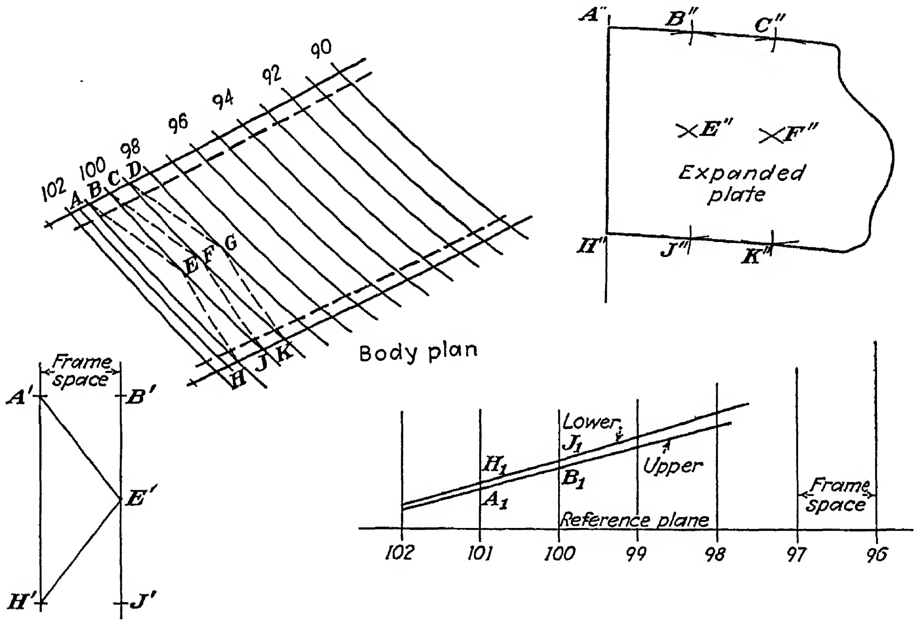

Fig. 69.

plicated and takes more time, but the results are improved accordingly.

The *triangulation method* divides an area to be expanded into many parts. In addition, in some applications, it depends on the principle that certain curvatures may be less abrupt along lines not parallel to the frame or station planes. We shall describe the simpler procedure first.

Figure 69 shows an example of the triangulation method. It is generally applicable as far as principles are concerned. In the body plan, we have a plate with laps and butts indicated. *A*, *B*, *C*, *D*, *H*, *J*, *K*, etc., are intersections of frames and plate edges.

E, F, G, etc., are points midway between A and H, B and J, C and K, etc. Midway points are joined to the edge-frame intersections as shown in the body plan.

The diagonal lines are planes, and therefore AE equals $B'E'$. In other words, between frames 101 and 100, distance AE is constant and equals $B'E'$ when laid out on the true frame spacing as shown. By joining E' to A', we get the true length of $A'E'$, or $A''E''$ on the plate. Likewise, HE equals $J'E'$ in true length, giving $H'E'$.

Spot A'' on the loft floor for the plate lay-off. By bending a batten around the frame at AH, we get $A''H''$ equal thereto. With A'' as a center, strike an arc to get E''. $A''E''$ equals $A'E'$, and $H''E''$ equals $H'E'$. This gives the true position of E''.

With a batten, measure EB. With this as a radius and E'' as a center, strike an arc to locate B''. As previously described, upper and lower plate edges can be expanded. With A'' as a center and a radius equal to A_1B_1 (expanded edge), strike an arc locating B''. With H'' as a center and a radius equal to H_1J_1, scribe an arc locating J''. By this process, points on the expanded plate can be determined. A faired curve through these points gives the expanded plate.

The degree to which a plate is divided by the triangulation method of expansion depends on the curvature of the finished sheet. If little shaping is involved, the diagonal line could go from plate edge to plate edge instead of to the mid-section of the sheet. This simplifies the work somewhat.

We shall now describe the use of the triangulation method where much curvature exists and where the plate is divided into more than two sections. This expansion is similar to the method just described, but it involves more detail. We shall confine ourselves to one end of the plate only, for a repetition of these operations carries the process to completion.

The first step consists in expanding the plate edges by the usual methods. As stated previously, the edges are as they would appear on a diagonal plane. From this expansion on edges, we can get the length of the plate edge between any two frames.

On the body plan, locate E, F, G, H, etc., about midway on the frames (see Fig. 70). Below this on the body plan, because the curvature increases, we divide the bottom half into two parts by the points J, K, L, etc., located at the quarter part.

At some convenient place on the loft floor, lay off $A'M'$ equal to AM as measured on the frame with a batten. Now we have to locate E'.

On a large scale for frame spacing (true) (SE_1), lay off E_1F_1 normal to the base line. This distance E_1F_1 equals EF and is the normal horizontal distance between these frames. Now, draw straight line ARM. Make F_1R_1 equal to ER. ER is the measured distance between straight line ARM and the frame AM.

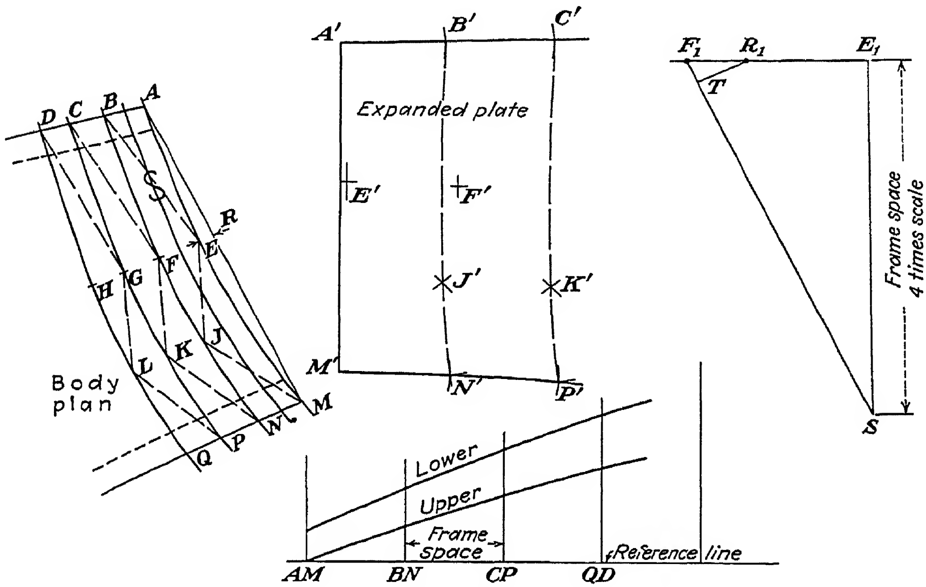

FIG. 70.

Connect F_1 and S. Draw R_1T normal to F_1S. Then F_1T is the horizontal distance of E' from $A'M'$. The vertical distance of E' above M' can be measured with a batten along the curve ME.

With E' as a center and EB expanded as a radius, strike an arc near the upper edge of the plate. $A'B'$ radius comes from the expanded edges. The intersection gives the position of B'.

With E' as a center and EJ expanded as a radius, strike an arc for point J'. With M' as a center and MJ expanded as a radius, strike an arc for the position of J'. $J'N'$ and $J'B'$ can be lifted from the body plan with a batten. N' is definitely located by an arc with M' as the center and the expansion of the lower edge as the radius.

Connect $N'J'$ and B' with a faired curve.

We continue this process for F', C', K', P', etc., until all points on the plate and on the edges have been located. Faired lines through the points on the edges will give the expanded shell plate.

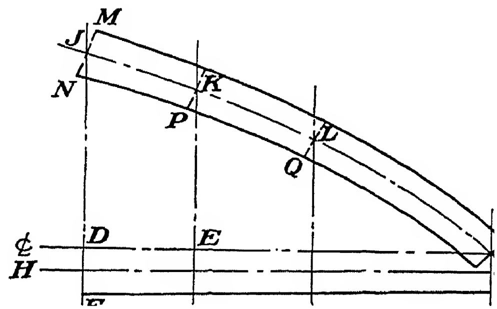

Fig. 71.

If it is desirable, more points like E and J can be used. The need depends on the curvature of the plate under consideration.

Decks in aircraft introduce a special item worthy of attention in the form of stringer plates. Owing to the curvature at the sides of a hull, the stringer plate is a mold-loft layout requiring particular consideration. If the deck is level, we are concerned with the taper of the stringer only. If the deck has sheer, we are concerned with the expanded layout.

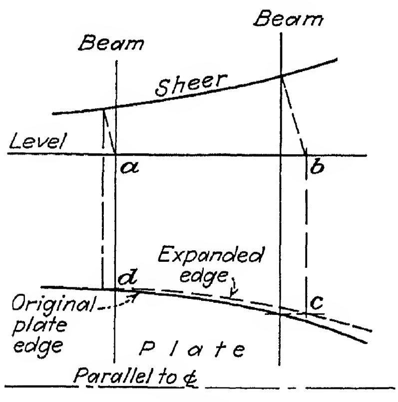

Fig. 72.

In the case of a level deck, on a half-breadth view, extend the frame lines beyond the center line as shown (Fig. 71). Let AB equal half width at the end. Lay off DF equal to the plate width on frame D. Lay off AG equal twice AB, and join F and G. Draw in the plate center line HC. Plot J, K, L, etc., by making $JM = HD$, etc., and square to $JKLA$. Locate the inner edge of the plate N, P, Q, etc., by laying off the width of the plate at each frame and normal to $JKLA$.

Where the stringer has sheer, it is necessary to girth the sheer line to get the expanded edge. Only a small portion of the con-

struction is shown in Fig. 72. A batten along the sheer marked to indicate beams and straightened will give *a*, *b*, etc. *a*, *b*, etc., are projected parallel to the beams. Where beam and original plate edge intersect, draw a line parallel to the level line. Where this line intersects with projected *a* and *b* as at *c* and *d*, we get points for the expanded edge of the stringer. A fair line through these points gives the expanded edge.

The inner edge expanded can be established likewise.

Ribbands and Harpins. In ship construction where the erection of frames involves positioning until strakes of shell plating are secured in place, ribbands and harpins are used. Ribbands are of wood, placed on the outside of the frames. They are straight in the afterbody and follow the sheer in the forebody. On account of the curvature in some vessels, harpins, or beveled angle irons, are used. Common harpins, sheer harpins, and stern harpins are applied as indicated by their names.

Ribbands and harpins are lifted from the mold-loft floor with all the care and accuracy that are used for frames and longitudinals. This is necessary in order that assembly may be accurate. Girthing is the practice, to find expanded lengths and true positions for fastenings. Harpins are beveled to form a good fit with the frames. The layout for ribbands and harpins requires no special explanation, for the practice for other ship parts applies equally well to these forming pieces.

Airplane construction eliminates the use of harpins by incorporating jigs and fixtures to support the structure until longitudinals and stringers can be put into position and secured. With airplanes relatively small in over-all size, the use of frame molds, keel jigs, and similar jigs in which to make assemblies is by far superior to the practice followed in ship construction. Nevertheless, aircraft are increasing in size rapidly, and the point may be reached where jigs will become too large and cumbersome to warrant their continued use. In that case the simplicity afforded by ribbands and harpins may have advantages.

Most of the information for ribband and harpin templets comes from the body plan. By positioning them in the body, we can work to the half-breadth plan and develop true lengths and true shapes as may be desirable. The top edge of ribbands and harpins is kept square and becomes the reference line for locating them in the construction.

Harpins can be made of any section size that may be convenient. Angle iron is particularly suitable, for it lends itself to shaping and beveling.

Fairing. Every airplane has a certain amount of trimming to fill in where improvement in air flow is desired—for instance, where struts meet the wing surfaces, where wing meets the fuselage, where tail surfaces meet other surfaces, where landing gear must be faired to reduce drag, and in similar cases. Most of this fairing is sheet metal material formed to fit neatly to itself and to the adjoining parts.

Fairing has two sets of curves to be considered. The first is the fit to the part to which it is secured, which is a form unto itself. The second is the form that the fairing takes in its own right. Both these amalgamate in the finished piece, but they demand individual consideration. Where the fairing meets the part to which it is attached, its section becomes a tangent to the other parts. Its own form insofar as section is concerned is ordinarily an arc of a circle or some other regular curve.

The line lay-off will give the form of the wing, surface, and fuselage or other main part. The line drawings for the fairing will give the lines at main stations and at a few intermediate stations. This is not sufficient for a fairing with much change of shape. Before any attempt is made by the loftsman to produce templets, it is best for him to make a layout of fairing lines with several intermediate stations, buttocks, and water lines. This layout will give a suitable picture of the whole.

Although templets can be made to show the form at all the intersections, it is believed advisable to make a full-scale solid form of wood, plaster, or clay so that true dimensions can be portrayed. The use of such a mold will be particularly useful in making the drop-hammer dies that are used to form the fairing parts.

The solid form must embody all pertinent information, with special reference to the frames, water lines, buttocks, etc.

Clear-cut expansion of deeply curved fairings is not practical. The size of sheet for the parts can be estimated only.

Figure 73 shows section lines for fairing around the leading edge of a fin and the leading edge of a stabilizer and around the fuselage. Only the body and profile views are shown. The half-breadth view is needed to make the lines complete.

To draw an oval (Fig. 74), given the long and short dimensions: Draw AB equal to the long dimension. Bisect it at C. Lay off the small dimension DE so that $CD = CE$. Through A and B, erect perpendicular lines with lengths AG and $FB = DC$. Bisect

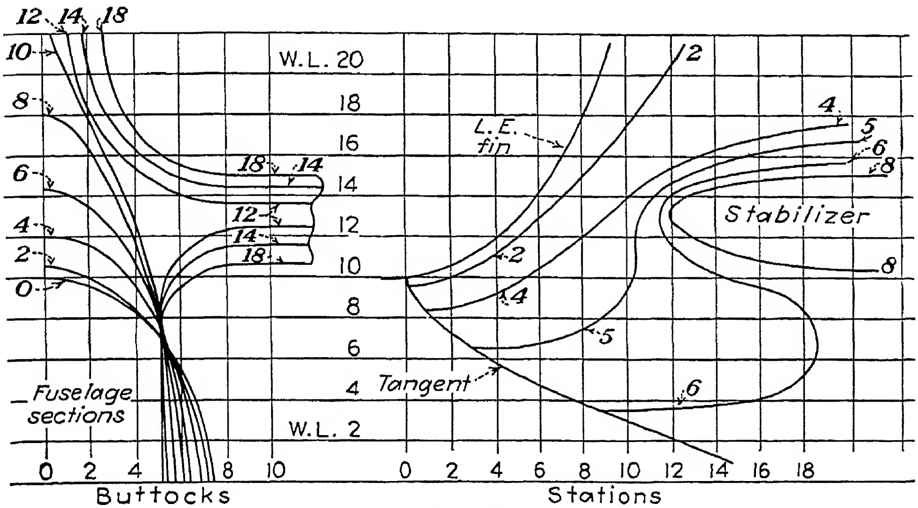

Fig. 73.

AG and FB at H and J, respectively. Draw HD and JD. Draw GE and FE. Note cutting at N and P. Bisect DN and DP at Q and R. Drop perpendiculars from Q and R meeting ED at O. Draw arc PDN with O as center. With radii approximating

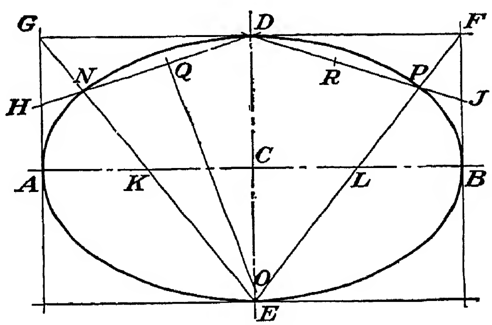

Fig. 74.

KA and LB, draw arcs NA and PB tangent to arc PDN through points A and B. If the minor axis of the oval is greater than two-thirds the major axis, the radius of arc NA will be greater than KA. If the minor axis is smaller than two-thirds the major axis,

the radius of arc NA will be smaller than KA. Complete the opposite side in the same manner.

Engine Mounts. The customary radial engine mounts are built as tubular structures secured directly or indirectly to a monocoque structure by bolting or pinning. There are other airplane parts, including complete fuselages, that are constructed by welding steel tubes to each other so as to form a rigid structure; but the principles on which the engine-mount structure is

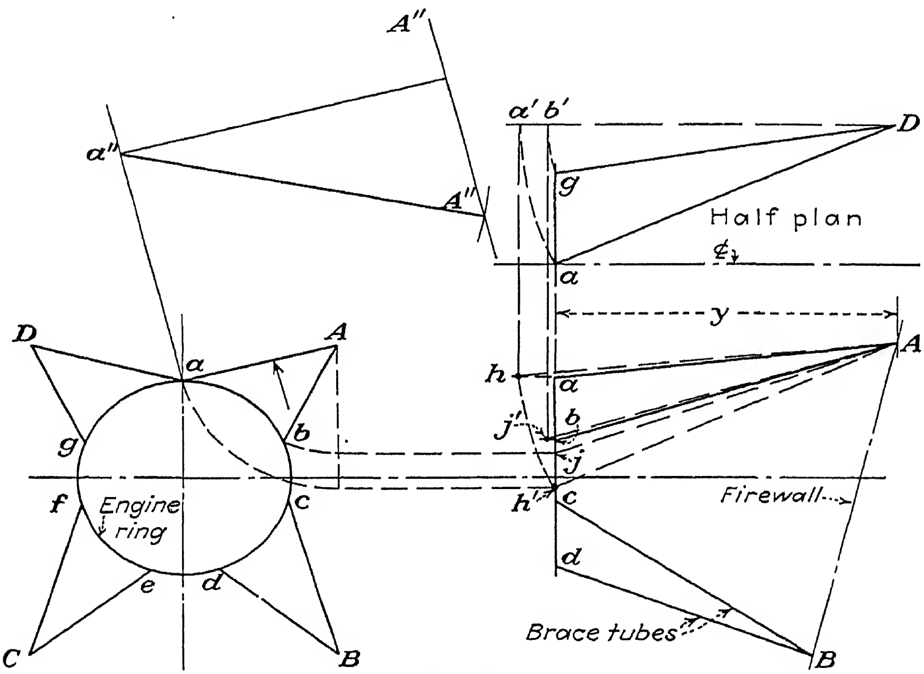

Fig. 75.

based are sufficiently broad and effective for the latter to serve as a typical example for other tubular structures.

Normally, the three-view drawing will give projected angles and lengths of the parts. The mount itself consists of an annular ring to which the engine bolts. From this ring, brace tubes extend to the fuselage fire wall. These tubular members meet other tubes or fittings which, together with gussets, wrapper pieces, etc., become the whole. Now, the three-view drawings are inadequate for the mechanic without the loftsman's templets showing true angles, true lengths, and true intersections.

Let us consider a tubular mount diagrammatically shown in Fig. 75. We have points of brace-tube attachments shown in the front elevation as a, b, c, d, e, f, and g. The space between d and e, called *eccentricity*, allows the carburetor to project down through the supporting tubes Bd and Ce. Spaces bc and fg, best seen in the side elevation, allow space in the side bays for other power-plant items such as starters and fuel pumps.

Let us determine the actual lengths of the brace tubes Aa and Da which are identical because of symmetry. In the plan view, swing a about center D to a'. Project down to the side elevation intersecting at h, with the side view a projected horizontally as shown. Ah is the true length of the tube. A check may be made by swinging a about A in the front elevation to a point vertically below A. Project to h' in the side elevation. Ah' is equal to Ah, the true length of Aa.

Next, we shall determine the true length of Ab or Dg which also are identical because of symmetry. In the front elevation, swing b about A to a point vertically below A, and project to the side elevation j. Aj is the true length. Check by utilizing the plan view as follows: Swing b or g (plan view) about D, intersecting a horizontal through D at b'. Project to the side elevation j'. Aj' is equal to Aj, the true length of Ab. Lengths of the other members may be determined in a similar fashion by using any two views.

The lugs at A, D, B, and C have definite angular relationships with the fire-wall plane and consequently with the engine-ring plane. Owing to this condition, it is necessary to determine true angles made by the brace tubes with relation to some reference plane. This can be done by the use of auxiliary planes and the information given so far. It will be noted that the horizontal distance from the engine ring to a vertical plane through A and D is constant. Also, the horizontal distance from the engine ring to the plane through B and C is constant. We know the lengths of the brace tubes. Consequently, we can project any number of auxiliary views to get true angles.

Let us take brace aA as an example. Project a view along the arrow perpendicular to aA in the front elevation. Draw a line through a perpendicular to aA. At some convenient point, plot a''. Parallel to aa'' and at a distance therefrom equal to y, lay off plane $A''A''$. With a'' as center and radius Ah (true length

Aa) cut $A''A''$. Draw $a''A''$. This is a view in the direction of the arrow. The angles made by this brace $a''A''$ with the mount plane and with plane $A''A''$ can be measured. Similar means can be employed to get other true views and true angles.

A common type of shear joint is shown in Fig. 76. The center lines of the brace tubes are made to intersect at the center of the attachment bolt to avoid eccentricity. The tube carrying the greater load becomes the major member, and the adjacent tube is cut and formed to weld with the necessary gussets and reinforcements to this main member. Slight misalignment in any of these supporting members will distort the mounting ring at assembly.

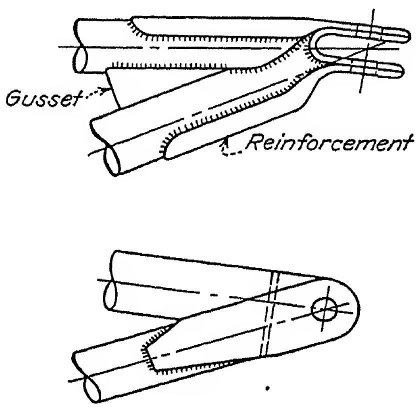

Fig. 76.

Plumbing and Conduit. As with any construction, pipe lines for plumbing and conduit are in the way of most other installations. Fuel lines, oil lines, hydraulic leads, and conduit extend into all parts of an airplane, interfering with their space, their support, and their connections. Besides these smaller pipe lines, heat and ventilation conduits with the intricacies of muffs, valves, lagging, etc., make the problems increasingly difficult.

In aircraft construction, all lines are designed with a view to lightness of installation. This means that direct leads are best. But the structure and other installations will not permit straight-line leads in the majority of cases, and so it is necessary that ingenuity be exhibited in the layout of the lines, to maintain lightness and yet accomplish the necessary clearances with nice consideration for supports.

The loftsman's concern is to give the shop pipe lengths and the final shapes for each piece entering the particular system concerned. Because too many complications will arise through promiscuous installations, there are two procedures either of which, or both, ought to be considered as a general arrangement. One is to lay out pipe lines on a copy of the full-scale line drawing. This drawing marked with the various airplane installations as

releases are received from the engineers should serve as a basis for preventing installation interferences. The use of such a composite full-scale drawing will be limited in solving some of the many problems that are bound to arise.

The other method is to use a mock-up. A mock-up of the engine-accessory section is particularly helpful as an advance notice as to the proper arrangement to be followed. Other mock arrangements are equally valuable where it is desired to make parts before the airplane itself is available. It is not worth while to hold up the construction of an airplane to permit the taking of measurements for parts to be made. The main intent of the loft is to make such a procedure unnecessary.

From the mock-up or from the layout on the line drawing, pipe lengths and their shape can be measured. With one end of the piece as the zero dimension and with a vertical center line, bends can be exhibited by length to the bend,' the azimuth of the bend with reference to the vertical center line, and the angle of the bend. This gives one bend. If we start with the particular bend farthest removed from the zero dimension and give the necessary data for each bend in order toward zero, we can tabulate all bends in a pipe piece. For example,

Piece No. 30*A*

Bend number	Distance	Azimuth, degrees	Angle bend, degrees
1	55	40	90
2	32	21	30
3	12	0	10

The only thing not given in the table is the radius at the bend. This is standard for pipe sizes excepting where a special radius is concerned, in which case it should be given.

Even if the pipe dimensions are taken from the mock-up, the tabulation is the best presentation for the shop. If another method is desired, the loftsman can make a bend templet by using a heavy wire shaped to parallel the center line of the piece of pipe concerned. The loftsman should take care in labeling the piece.

Having the pipe and its shape, we now need only establish the support points. These should be indicated by drawing,

templet, or tabulation so that full information will be available to the installation shop.

The intricacies involved in heater and ventilation lines demand a mock-up where intersecting lines complicate the problem. Full-dimensioned wood or metal imitation is necessary to give proper view to the assembly of the parts concerned. Loft layout is needed for the mock-up, but full data cannot be expressed in a two-dimensional layout unless the matter has some degree of simplicity.

Struts and Wires. Being a form of column, struts have only one dimension that is of importance to the loftsman, *i.e.*, the length. The most difficult feature in obtaining the length is rabbeting the strut center line into a plane from which a dimension can be lifted.

External struts, usually streamlined, find application in float installations, in biplanes, and as masts. In very few cases do struts fall into the main planes of our line layouts. Consequently, the true length and the true angles of position are not exhibited in the common views with which we deal. Rigid machined joints as terminals fitting into rigid fittings in the airplane structure make it essential that angles and dimensions shall be accurately known, for the tolerances allowable are too small to permit inaccuracies to be taken up.

A system used in engine mounts and like structures can be applied to struts in general. This consists in rotating the plane in which the strut is to be shown until it coincides with the strut axis. The rotation can be effected about a terminal, as was indicated in Chap. II under Descriptive Geometry, for an auxiliary plane view. Sometimes, more than one rotation is necessary about more than one axis; in this case, each rotation should be handled independently and in order.

It may be necessary for the loftsman to include the fittings with the strut in making his rotations so that the fittings will be laid out accurately.

Because this type of lay-off is explained in detail under Engine Mounts, for a similar problem, it will not be analyzed here.

Wires are fitted with adjustable terminals for giving take-up. The problems involved in determining the wire lengths are the same as for struts, excepting that the amount of adjustment possible allows a large tolerance. The angle of the wire position

must be determined in the same manner as for struts, with approximately the same degree of accuracy. Wire tangs do not give any leeway for bending, it being essential that applied tensions are in the direction contemplated by the design.

Armor. The use of armor plate in military aircraft introduces a feature not previously encountered in airplane construction. Like shipyards, aircraft plants do not have facilities for working armor to make it fit its installation. This is due to the fact that heavy machinery and special processes are needed for armor construction, from the raw material to the final finished pieces. Consequently, it is essential for the maker of the armor to have an accurate drawing and templet for each piece to be made, so that the finished piece will go into place with no work other than bolting into position.

An armor plate when finished must be true in shape and size. All securing holes are drilled. Brackets and any other mounting items are in position. This means that armor must enter the airplane construction at an early stage and that other parts securing to the armor are fitted to the armor, and not vice versa. To the loftsman, it means that armor templets are made very early in the schedule of operations and that extreme accuracy in laying out the templet is an essential. If conditions so permit, it may be advisable to test the templet in the sub-assembly of the airplane before it is finally released. This can be done by making duplicate templets and by trying the duplicate in the construction before the armor maker reaches the drilling and hardening point in his operations.

An armor plate is a simple shell plate. It is lifted and laid off in the same manner as a shell plate. The loftsman, being used to thin sheets, must take thickness into account in handling armor. With the line and other structural layouts, the armor plate is laid out on the loft floor to full scale. Because controls and equipment might interfere, it is necessary to take their installation into account. Full dimensions are inserted on the floor lay-off. Most of these can be indicated geometrically; but, if not, the lines must be shown as exact. The templet is lifted from the floor lay-off. The templet should be made so that it will not distort in handling. For this purpose sheet metal, plywood, or plastic will serve better than paper or wood patterns. Some armor plate will require securing brackets, angles, or other

shapes, owing to the character of the construction. Templets of these securing structures are made at the same time that armor templets are prepared, so that they will conform.

As will be seen from the sketch of a plate illustrated (Fig. 77), all dimensions are given from reference center lines or plate edges. Centers of holes for the bolting are established so that the plate bolts directly into position. Any tolerance allowed must be taken up in the structure to which the plate secures.

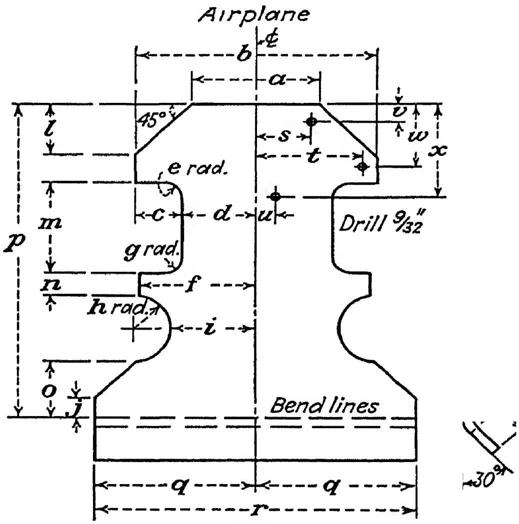

FIG. 77.

Pertinent data such as thickness, tolerances, hardened face, material, and part number are applied to the templet or recorded on the drawing.

Windshields. The use of molded glass and transparent plastic has made it possible to make windshields in the aerodynamic form required. The structure supporting the transparent elements follows the usual rules insofar as layout and development are concerned. The transparent portions are preformed to make a neat fit and to give the shield the outside continuity essential to low drag at high speed. At securing points the glass or plastic requires clearance to allow for contraction or expansion.

Although aircraft manufacturers are outfitted with means for forming plastics, they have no facilities for shaping glass. But, in either case, accurate templets of the final form for the parts are necessary. This requires complete lines to full scale so that dis-

crepancies will be prevented. A shaped solid form of wood or plaster for each piece seems advisable so that the finished piece can be laid on the form for checking. There is only one other point that is vitally important. Because aircraft are subjected to frequent temperature changes varying from the frigid to desert heat, it is necessary that allowance shall be made in fastening glass or plastic plates so that the plates can contract and expand freely. To some extent the airplane itself will distort under varying loads which introduces an additional reason for expansion and contraction allowance. Considering the sizes of glass and plastics now in use in aircraft, a full $\frac{1}{16}$-in. allowance is believed to be sufficient. If bolts go through the plate, each hole in the plate should have ample clearance. It may be advisable to cut the hole through to the edge if no good reason can be advanced against this.

Because windshields are in the nature of housings, watertightness in construction is essential. The usual method for accomplishing this is to set the glass or plastic sheets in rubber.

In proceeding with a lay-off for the windshield the loftsman obtains his data on form from the line lay-off. That portion of the hull or fuselage covered by the shield is laid out as the base. Fuselage or hull lines are affected by shell-plating thickness, and therefore correction is applied. Fixed portions of the windshield are then laid off to suit the lines of the shield and the fuselage lines. If the canopy includes a sliding portion, the track of the sliding part is laid out. Three views of the track are needed to be certain that the positioning does not cause spread or distortion. Where needed, forms and templets are made to guide the manufacture of parts and to direct the correct assembly.

Separately from the above but with the fixed points and the track as a basis, the sliding canopy is laid out. Extra lines should be developed where curvature is not simple and uniform. Before the canopy parts are developed the loftsman must check the layout against the fixed parts of the shield and the airplane structural layouts to ensure clearance. This must be done in the closed and open positions, with additional checks for any critical intermediate positions. Templets and forms made for the sliding parts ought to be compared with mating templets on the fixed parts. From that point on, the handling of expansion, development, and form templets follows the practices used in the fuselage

structure, consideration being given to the special factors mentioned.

Movable parts of windshields demand controls. These control systems warrant complete detailed layout and attention, for the difficulties of the pilot affect the whole life of the airplane if the control system is not effective, easy, and simple. The loftsman can be of material assistance by laying out the controls with a view to the three-dimensional aspects and to the operating conditions involved.

With pressure cabins the need for effectiveness in controls becomes paramount, for distortions due to pressure may become such as to interfere with the maintenance of the seals. Unusual care is demanded of the loftsman in handling doors, hatches, and similar airplane parts where pressure conditions exist. In many respects the matter approaches submarine requirements in layout and loft work generally.

Controls. Cable controls and rod controls tend to interfere with other installations when they enter the assembly of an airplane. Whether or not it is possible for the loftsman to lay out controls so that they will avoid the structure, the equipment, and other parts depends largely upon how fully these items have been entered on the control layout. Either a half- or a full-scale layout should be available to the loftsman for the entry of the construction that may have a bearing on the control leads. The same layout can be used for pipe lines, conduits, and other installations secured to the structure but not necessarily a part thereof.

Controls may be rods, cable, or some special mechanical means for imparting motion through transmission. Various kinds and forms of linkage enter the systems. In late airplane designs, electrical and hydraulic means of control are increasing and are supplanting mechanical systems. Here we shall limit our discussions to rods and cables as being of most interest to the loftsman.

The loftsman is concerned with lengths, positioning, and space in laying off information on control systems. The leads for controls are furnished by the designers. In laying these out the loftsman has some freedom in positioning brackets and guides so that interference is prevented. Having positioned the leads the loftsman can furnish the essential lengths for the various parts by lifting the data from the lay-off.

In making the control lay-off the loftsman can indicate extremes of movement in the actual installation so that sufficient clearance will exist under all operating conditions. If a full-scale mock-up has been built, it is advisable to check control leads there as well as on the floor. In some cases, it may be advisable to have controls made so as to permit adjustment to length in the actual installation. For instance, in a cable, only one end can be spliced, the other end being left raw for measurement in the airplane assembly. In any case, the loftsman should make a note of lengths for record and future reference.

Tanks. There are two kinds of tank used in aircraft for fuels. The integral tank, built into the structure, utilizes the structure insofar as that is possible. The separate tank is independent of the structure and is removable as a whole. The removable feature makes the separate tank advantageous from all points of view excepting that of weight. Because replacement is practicable and fuel-tank leakages are not uncommon, the separate tank is an essential where the cost in weight does not preclude such design. Oil tanks are invariably separate tanks, for their size is not great enough to warrant the complication attendant upon any other kind of installation.

The integral tank, being a part of the structure itself, has the advantage of being a fuel-tight structural construction. If the tank is built into the wing, the wing covering becomes the shell and solid ribs become bulkheads. Other strength members are carried through the tank volume as may be required. The loftsman is concerned with two features in laying out the structure in an integral tank. The first is, in all respects, to ensure a fuel-tight job. Faying surfaces must be equal to those existing in watertight construction. Proper allowances must be made for stopwaters and gaskets. The second is that to ensure, with respect to the laying out of all riveting, a fuel-tight job. Usually, watertight spacings will give satisfactory results, but troubles at corners and in complicated arrangements must be eliminated by precision layout and execution. Although integral tanks are not favored for military aircraft, the features required by this kind of construction are demanded for other purposes in military aircraft.

Separate fuel tanks (see Fig. 78) take a variety of forms and constructions. They may be regular or irregular in shape. They

may be welded or riveted. They may have heavy shells with no baffles or be thin-shelled and extensively baffled. They may fit into the wing or into the fuselage. In general, they are quite variable in character.

Oil tanks, being installed in the engine-accessory compartment, are usually irregular in shape and without baffles.

All tanks, regardless of purpose, have a number of pipe connections, some of which are large enough to warrant special care in the development of the intersection. Smaller connections can be made by using fillers to take up irregularities.

As with the structure, the loftsman must provide templets for the shell expansion and for baffles. If the tank is irregular,

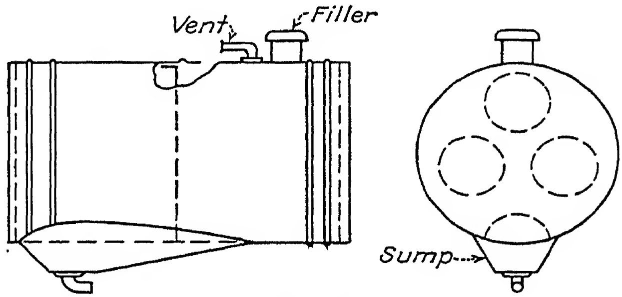

FIG. 78.

extended assumptions must be made regarding the development of the shell. With regular shapes the expansion of the shell follows geometrical rules. In addition to the developments, the loftsman furnishes required information on the tank shape. This may resolve itself into simple three-view sketches, or it may entail wood patterns.

If the tank is small and irregular in shape, it may be best to make a solid wood replica so that the construction can be studied in full scale. The joints can be indicated on the mock-up. Connections should be secured to this mock-up so that they can be truly represented and tried out in the supported position of the tank.

If the tank is large and irregular in shape, a skeleton form can be worked up to represent the tank. Such a skeleton form will serve a number of purposes besides that of giving correct information on the contour. If the seams to be joined can be indicated, this will give the mechanic the basis for developing the shell.

It can also serve as a try-form for parts of the shell, which are pressed or hammer-formed.

The loftsman with the aid of a draftsman should be able to calculate the volume of the tank from the full-scale lines of the tank. This information is necessary to check calculations made on the basis of small-scale drawings. This calculation can be done by the use of Simpson's rules and areas of sections obtained with a planimeter. Owing to differences in surface levels as between the airplane in flight and the airplane on the ground, it may be necessary to make calculations for each condition.

Because tanks must fit snugly into their supports, the loftsman must check the lay-off of the structure into which the tank fits in the airplane. This should include a check on the hold-down straps or other means of securing the tank into position. The final check is for clearance for the fittings that become the tank connections.

CHAPTER VI

SPECIAL APPARATUS AND PHOTOGRAPHIC REPRODUCTION

General. Credit for the development of the basic principles inherent in the technique used in the mold loft rests with the shipbuilding industry. In its early application to the aircraft industry the airplane loftsman followed the leads set by the shipbuilders. Although the details of construction have been decidedly different the mold-loft practices have been similar. It is possible that deviations that are beginning to appear may be a transition stage only; but, in view of the many differences in the problems involved, it is quite possible that the ship mold loft cannot follow the procedures found beneficial to the airplane mold loft.

It must be understood that ships are individually designed and constructed. Duplication occurs infrequently; and when it does occur, simultaneous construction is the exception rather than the rule. Although groups of ships could be built to the same loft lines and templets, the time element is such that like parts would not be made one right after the other as is the case where quantity production is involved. Generally, the ship loftsman is concerned with individual ships, each case being new at the time that the vessel is laid down. It is true that the whole matter is not repeated where like ships are involved, but it does have the aspects of a tailored job without any extended application of quantity-production principles.

In another, more important way the ship differs considerably from the airplane insofar as the loft is concerned. Ships are large, utilizing structural members of major proportions. This means two things to the loftsman. First, the scale and, consequently, the tolerances are vastly different. Second, when a part for a ship is made, the amount of "horsing" of the piece that is possible is limited. The first demands that a formed part shall be made by skilled mechanics who can shape such a part

without the benefit of much machinery. And the second demands that when the part has been shaped it must fit properly or the full benefits of the mold loft will not follow.

On the other hand, the airplane is produced on a semiproduction basis. Of course, the experimental model is an individual case; but, after that, the quantity handled at one time runs into the hundreds. A particular part is made up in large lots at one time to save on production costs and time. Even where the part is intricate and takes much hand labor to produce, the current methods tend toward making parts in lots rather than individually. Naturally, this procedure makes for a different arrangement in loft practice than would be the case in a ship mold loft. Even where experimental airplanes are involved, there is a strong tendency in the loft to regard the matter as inclined toward quantity production rather than otherwise.

On the score of relative size of material handled, all airplane parts are light and easily produced. The materials are machine-formed for the large part; and once a part has been proved to fit, it is made in its entirety before it enters the assembly. Making templets for parts that can be worked on in place duplicates the shipyard practice in many ways; but where a piece is to be finish-drilled before it comes near the assembly, is a practice that calls for special effort on the part of the mold loft. It is in matters of this kind that the aircraft industry must develop a skill and a procedure peculiar to itself and wherein ship practices can no longer be followed.

From this brief discussion, it can be seen that there is no particular reason why the airplane industry should not adapt the values of the mold loft to suit itself. If we allow some degree of elasticity in the functions of the mold loft, there is no doubt that it can improve the manufacture of airplanes and broaden its sphere of action. Each airplane manufacturer will find his own way to carry out immediate requirements; but, in time, procedures will approach some form of standardization. In this respect, it is believed that the mold loft holds forth a good promise of becoming a main tooling center in any aircraft manufacturing establishment.

We consider the mold loft as the producer of templets that are to be used in making parts from sheet and shapes. We also regard the loft as the source of templets that are used to make

jigs, fixtures, forms, and patterns. If we extend our viewpoint on the ability of the loftsman, we shall find that it is logical to assume that the loft is in a good position to make all the jigs, fixtures, forms, and patterns required, not only for structural parts and assemblies, but also for fittings, controls, pipe lines, and other items that must be adjusted in respect to size, form, and fit to the airplane structure. Certainly, the first source of information is the loft; and if the manufacture of the tooling is delegated elsewhere, the loft as a check should not be overlooked. The inside of an airplane is congested at best, and good regulation to get both structure and installations to fit neatly requires the skill of those who are familiar with the three-dimensional viewpoint. No attempt will be made in that which follows to cover all these points. They are presented merely to indicate that the airplane mold loft in branching out into new methods will do well to give thought to the application of these methods to the whole structure.

When hull, fuselage, and wing lines are produced in the drafting room to a small scale and then laid off, faired, and corrected on the mold-loft floor, it would appear that duplication of effort exists. If we were to eliminate that duplication, we should have to bear in mind that any practice put into effect should neglect none of the basic requirements of the original system. The drafting room needs line drawings to develop the structure, to make wind-tunnel models, to develop equipment installations, to study calculations, and to have a record. On the other hand the mold loft reproduces lines for fairing, for correction, and to have basic information that is necessary to produce templets, jigs, forms, and patterns. The basic information results in means for selecting raw material for parts and for actually manufacturing the parts. Naturally, it leads to sub-assembly and assembly of parts. The drafting room small-scale drawings are not, and cannot be, exact—the mold-loft data must be exceedingly accurate. A cooperative effort, between drafting room and mold loft, in handling the development and establishment of lines ought to lead to an improvement—at least, economically speaking.

If all lay-offs were developed in the first instance to full scale with an accuracy equal to that needed in templet making, two features would be necessary for this method to serve as a substitute for the normally current systems. The first is that it

should be possible to reproduce the lines without having to resort to laborious measuring and recording. The second is that it should be possible to reproduce the lines on a smaller scale than full size. We could then make prints, both large and small, in whole or in part, that would meet all the original requirements. Thus of course, some tedious operations would have been eliminated, such as that involved in recording off-sets. Also, all the extra prints of full-scale lines that multiple manufacture of templets may require would be available. For the time being, we shall let the matter rest, with the statement that photographic-reproduction processes, or similar methods, seem to be the answer.

Ordinarily, and insofar as the designers are concerned, the structure of an airplane is shown by means of major-assembly drawings. These drawings give complete information regarding the whole of an assembly. They give data on parts of an assembly only insofar as the part appears in its assembled position. To a great extent, typical constructions must be followed wherein much is left to the imagination. The work of building an airplane from such drawings without going through the process of laying off the job to full scale is one that experienced mechanics would find difficult. If the draftsman were to rely upon his small-scale drawings to give him the dimensions of all the parts so that he could prepare a drawing of each part in detail, he would find that his work involved great probabilities for error. On the other hand, by using loft lay-offs of the structure, the draftsman would find it relatively easy to make complete and detailed drawings of parts, sub-assemblies, and assemblies. These would still be drawings, subject to the distortion and the extended dimensioning inherent in drawings. Photographic reproduction or mechanical development constitutes a definite step forward in accomplishing the desired efficient procedure.

There are one or two other factors that are worth mentioning in considering means for eliminating operations in laying off an airplane. The parts manufactured for a specific type of airplane must be interchangeable. Conditions of operation are such that all structural parts made to a design must be interchangeable with all other parts made to the same design. Where jigs, forms, patterns, and templets can be produced without any risk of errors or variations in tolerances, we come closer to ensuring

interchangeability. It is believed that there is much to be said for the claim that the use of mechanical development and photographic reproduction in laying off a craft improves the conditions for interchangeability of parts.

Large-scale production is feasible provided that all operations are based on principles applicable thereto. Control over the matter of time is one of these principles. After a design has been released, it is essential that several departments or shops of the airplane plant have their data as soon as possible. Elapsed time must be fully utilized, or a large, machinelike establishment will be idle. Consequently, as soon as a templet can be issued, several agencies need duplicates so that parallel progress is possible simultaneously. The hand-lifting process is too slow for concurrent issue of templets, whereas the methods to be described give the loft every opportunity to meet the demands enforced by quantity production.

The airplane loftsman is enjoined to pursue the application of mechanical and photographic reproduction to laying off in all its categories. The subject has experimental features that may give an insight into improvements in airplanes and the methods of building airplanes not now apparent.

Mechanical Reproduction. Owing to the fact that airplane structural parts are formed into shapes other than those of the raw material supplied, the loftsman must receive information as to the shape required and transform that to a means for shopwork. It has been shown previously that all shapes evolve to become lines—straight and curved. This permits us to discuss lines on the basis that they represent the shapes concerned.

As has been said, engineers provide data on lines in one form or another, these lines are faired by the loftsman, and the loftsman uses these faired lines to make templets. In speaking of lines here, we refer to all lines, be it for the airplane as a whole or for a structural part. The operations of laying off lines, fairing, and lifting of lines for templets take much time. So far, many schemes have been developed for the purpose of facilitating the lifting of lines for the templet. Of course, this entails the utilization of the special processes concerned in laying off the lines in the first place.

Let us consider a phase of this matter previously discussed. All lines—straight and curved—can be placed in two classifica-

tions, *viz.*, those which can be mechanically reproduced, and those which are not readily capable of being reproduced with mechanical apparatus. Straight lines and circular arcs are simple cases of mechanically reproducible lines. If the line takes a curve, however, it may be difficult to reproduce that curve excepting by the methods commonly used by loftsmen. Taking off-sets, measuring, and copying permit the loftsman to handle any line without reference to its classification; but such methods are slow and require care and skill. If we could classify curved lines so that they could be mechanically reproduced to any scale, we should have a method that would be of great importance to the loftsman. A hint as to these possibilities was given under the methods for producing airplane piping (Plumbing and Conduit, Chap. V). It was indicated there that instructions for making a pipe part required data as to distances and angles of bend only.

Many parts of an airplane structure are made with relatively simple lines easily reproduced mechanically. With proper reference planes, distances, and radii given, straightedges and compasses serve to cover considerable lay-off work.

Let us consider some of the simpler forms and see where they lead. A straight line can be established in space by its coordinates, whether the line is in axis planes or not. It is seen, then, that we can fix such a line as soon as we establish the reference planes or axes. It is not essential that we should make a lay-off to full scale to have data locating the line—coordinates give the information.

As has been mentioned previously, we can work from the straight line referred to a plane. Suppose we have a polygon shape in that plane. The polygon has straight edges, and this condition permits us to write ordinates for every side of the polygon. Here, again, it is not essential that we should make a lay-off on the loft floor to secure the shape. We can draw directly to the templet and proceed accordingly. The advantage is immediately evident.

The same reasoning can be applied to the establishment of circles in space. We need to know the coordinates of the center, the radius, and the plane of the circle. Of course, what is said of the circle applies equally to a circular arc excepting that we must have data on the degree of the subtended arc. Consequently, the circle can be mechanically reproduced anywhere if

we have tabulated data. And, in addition, the circle referred to will occur in the same place no matter who lays it off, provided that the same degree of accuracy is maintained.

Before going further, it may be advisable to apply these methods to an example. A flat-plate floor in a hull is to be laid off. The outside edges form a pentagon, we shall assume. If the plane is known with reference to the base line and the station line of the hull, it is very simple to lay off the size and shape. If there are lightening holes in the floor, it is necessary to give data on the centers and radii. From this information, we can proceed directly from a small-scale drawing to the templet without any lay-off on the floor. Of course, this is a very simple case, but it does illustrate effectively the possibilities inherent in the method.

If we want to flange an edge on the floor, this, too, is simple mechanical representation. Dimensions and angle of bevel serve admirably as the complete basis for the lay-off directly on the templet. By giving edge distances and rivet spacing, it is possible to put this information on the templet directly.

The extent to which mechanical reproduction can be carried out depends on many factors, the principal ones being the complexity of the design concerned and the shaping involved. But, provided that many parts of an airplane can be handled in this manner, it becomes a paying factor in time. It is true that engineering designers must be fully aware of the process so that they, too, will recognize the need for remaining within limits in their design of detailed parts.

When we begin studying the application of this mechanical development to solids, it is not so simple to explain the possibilities. It is true that section planes will give the form of the solid, but we must look at each problem from various viewpoints to obtain the full significance of the effect of section representation. Any solid that has flat sides can be resolved into surfaces capable of mechanical representations from dimensioned data. It is another matter, though, when the surfaces take on curved shapes. Consider cylinders and cones, including truncated forms. Geometry and trigonometry will give all the desired information. The loftsman can judge readily whether a lay-off will give results more quickly. If straight lines join the extreme planes or section planes, we can still handle the problems concerned without resorting to laying off to get at the form.

But let us take another case—where the end planes are joined by surfaces giving curved lines of sections. An example would be a fuselage or nacelle in which all frames are capable of mechanical development but in which radial planes intersect the fuselage lines in a curve. If this curve is the arc of a circle, we are still within the bounds of our method. But if this curve is not a simple circular arc, we enter the realm of complexity. Generally speaking, airplane hulls, floats, fuselages, and wings present sections that approach complexity. However, there are many portions of these parts, as well as other parts of the airplane, that can be mechanically reproduced and that the loftsman can lay off on the templet or pattern without going through the operation of laying off the item on the loft floor. Combining the simpler lines with standardized curves should give effective means for producing many templets and form tools now handled by the slower methods of complete lay-off.

It is a noticeable fact that the use of certain shapes becomes standardized with airplane builders after they have been used successfully. For instance, a fighter manufacturer will establish a certain fuselage shape that fits his manufacturing methods and that turns out to be a part of an airplane of good performance. For a considerable time thereafter, the manufacturer's fuselage lines will follow the original lines and shape, being scaled up or down to suit the size of craft concerned. The same may be true with respect to other parts of the airplane.

Another case of substantial standardization exists with respect to hulls and floats. Each builder of flying boats has inclinations toward a standard form of hull that he uses extensively in all boats that he designs. This individuality exists within a manufacturer's designs as long as the general characteristics of the airplane type remain the same. Even when a major deviation appears imminent, he will try to take advantage of forms and shapes with which he is familiar. The same holds true with respect to manufacturers of float-type seaplanes.

It is quite usual for airplane manufacturers to select National Advisory Committee for Aeronautics airfoil sections. These sections have known characteristics. Data on the off-sets are readily available. As a consequence, these airfoil sections have become standardized within the industry as a whole.

The effect of this tendency toward standardization of forms and shapes is that it is possible to develop sets of curves, similar,

but varying in size, that can be used for laying off the desired curved lines very quickly. The sets of curves could be made in wood, transparent plastic, or metal. They could also be made so as to take advantage of the pantograph transfer. Somewhat similar schemes have been used in the shipbuilding industry where ship curves, yacht curves, and other standardized curves in varying sizes are available. With such curves applicable to various parts of an airplane available to the loftsman and established within the plant as standard, it is possible to make lay-off of lines for fuselage, hull, wing, or floats very rapidly.

We have mentioned the standardized airfoil sections usual for airplane wings. If a wing has parallel leading and trailing edges, the section is constant for a large part of the wing. Station planes running perpendicular to the sections will intersect the wing lines in straight lines. Under those circumstances, we have a mechanical representation using standardized curves.

If the wing tapers in chord and in thickness, we have another case of standardized curves combined with straight lines. When we reach the wing tip, the degree of complexity depends on the design.

Fuselages lend themselves to mechanical development. Where complete accord cannot be obtained, it may be possible to use the standardized curves to bridge any gaps.

The decks and sides of floats may be designed with mechanical-dimensioned sections. But when we attempt to handle hull and float bottoms, we encounter too much complexity unless we can resort to curves usual and common for the designs being reproduced.

Until this procedure for the mold loft becomes extended, it is not possible to indicate the limits. It seems that there is a large field for exploitation open to the loftsmen who will approach the subject with care and deliberation, with an ultimate view to accepting those parts of the method adaptable to rapid production of templets, forms, jigs, tools, and patterns.

Mechanical Devices. Before we enter the subject of photographic reproduction, it is advisable to mention the working of a few instruments not usual to the mold loft but which may be of importance in their application to the problems presented.

The mold loft of the past has been regarded as a hand-operated shop. The newer methods involving instruments, machinery,

and specialized equipment have made no inroads on the home-made practices of the loftsman. Part of this has been due to a low rate of production, but the main factor has been the ingenious skill of the loftsman in working his own way out. But, con-

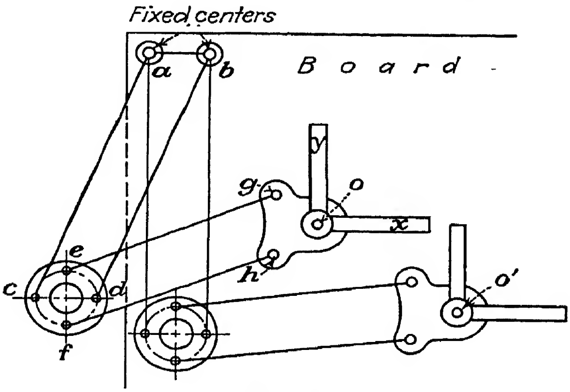

FIG. 79.

fronted with large volumes and with an enlargement of its sphere of influence, the airplane mold loft has had to seek some relief by mechanizing its semiskilled labor. In doing this, it is natural that some of the mechanical equipment come from tools that have been used in normal drafting-room functions. To give the student an inkling of some of these, we shall give brief descriptions of a paralleling machine, the pantograph, and the planimeter.

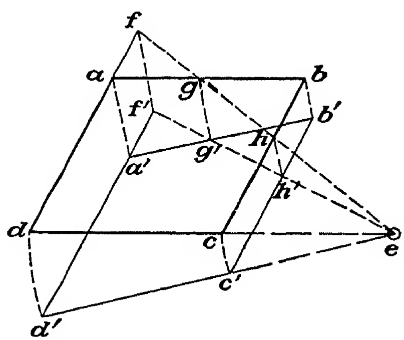

FIG. 80.

Parallel motion can be produced by a four-bar linkage system (see Fig. 79) such as is incorporated in the universal drafting machine. Linkage *abcd* is arranged so that *ac* and *bd* are always parallel. *a* and *b* are fixed centers. Linkage *efgh* is arranged so that *eg* and *fh* are always parallel. The head *XOY* can be swung into various positions on the board (see figure). In all cases, lines formed by straightedges *XO* and *YO* will be parallel to a previous position of these edges. If *X* and *Y* arms can be revolved about *O* as a center and the position clamped at will, we can vary paralleling lines relative to the board as may be desired.

The pantograph is of use in producing similar curves or in transferring lines (straight or curved) from one figure to another. It is of major value in transferring mold lines from the body plan to another sheet for templet-making purposes.

The pantograph is a four-bar linkage so arranged as to form a parallelogram *abcd* (Fig. 80). With a point in the linkage such as *e* fixed, certain other points as *f*, *g*, and *h* will move parallel and similar to each other, no matter what the form of the curve followed may be. Points *f*, *g*, and *h* lie on a straight line through *e*, and their motions are proportional to their distances from *e*, the fixed point.

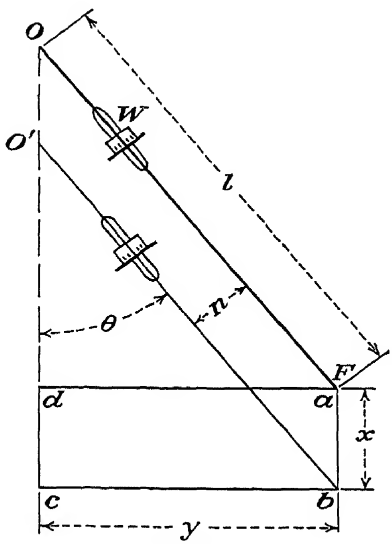

Fig. 81.

$$\frac{ff'}{hh'} = \frac{fe}{he} = \frac{de}{ce}$$

Pantographs are made adjustable so as to produce various ratios in the reproduced lines. By fixing the copying pencil on the same link, as, for instance, at *d*, as the tracing point *f*, a 1-to-1 ratio can be produced.

Pantographs available in the market are excellent instruments, with many possible adjustments to give controlled results of all kinds, useful to the loftsman.

The planimeter is used for measuring areas of irregular figures and for determining the mean ordinate of a curve. It may find other uses in the loft by being adapted to the particular problem involved. There are several kinds of planimeter in use, all being based on the same general principles. In Fig. 81, if *OF* is regarded as a link with a free wheel *W*, we have the basis for a simple planimeter. Wheel *W* is free to turn on *OF*. If *F* moves along *ab*, the wheel *W* will revolve about *OF*. If *F* then moves from *b* to *c*, the wheel will continue to revolve, the rate being dependent on the angle θ. Moving *F* from *c* to *d* produces no revolution, for movement is parallel to the axle. In moving *F* from *d* to *a* the wheel revolves in the opposite direction to which it moved when tracing *b* to *c*. When the point *F* reaches *a*, the

reading on the wheel should be proportional to ab. The area of figure $abcd$, the perimeter of which was traced, equals xy, which bears a direct relation to link length l and distance n. If the rectangle were infinitesimally small, we could regard any irregular figure as made up of such rectangles. The area of any figure can be measured by knowing length l and the revolution of the wheel u.

In a polar planimeter the plane of wheel W is on a radius from fixed point P (see Fig. 82). O is a link center. It will be noted that if F traces xx the wheel does not revolve. The base is then xx. The student can work out the effect of tracing the perimeter of an area near xx.

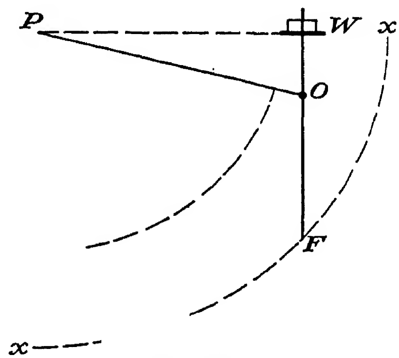

FIG. 82.

Tracing the perimeter of an area will cause the wheel to revolve so as to give a reading that can be used to determine the area. The wheel rolls and slips depending on the direction of motion. Accuracy depends on the axle of the wheel being parallel to the arm. Compensation is produced by measuring the curve areas right and left or by making several traces. The limits of areas that can be handled depend on the lengths of the planimeter links.

Photographic Reproduction. This is a new tool for the loftsman, which he has accepted from a desire to save time in laying off the airplane. Originally, this photographic-reproduction process was limited to reproducing templets. Although it has application to hull, wing, and fuselages lines lay-off it was not so applied. By using the photographic-reproduction processes to the fullest extent it is possible to detail the airplane structure on the loft floor from rather simple assembly drawings. First, to obtain a drafting-room record, a photograph of the lay-off on the floor is effective. Second, it is a short step to the projection of that photograph negative onto sensitized templet material, the projection being to full scale. The first step eliminates part drawings. The second step eliminates the tediousness of lifting the templet by off-sets from the loft-floor lay-off of the part. In brief, this is the way an important contribution to mold-loft

practice by pioneering aircraft companies was originally used by the loftsman.

From the steps briefly described above, photographic reproduction has been used in all branches of templet making in such a manner that many schemes involving this process are now offered as alternatives and improvements. Most of these have their inception in the procedures common to the lithographic, photographic, and stenciling methods. Before we discuss the variations, we shall analyze the particular photographic processes now used by the industry.

All the photographic methods in use in the mold loft reduce to the fundamental that a drawing made on prepared metal, prepared plastic, or the loft floor can be reproduced on paper, wood, metal, or other material. There are several ways in which this is accomplished. These can be classified as contact printing or photograph and projection printing. Although each has its advantages and disadvantages, neither has been in use long enough to warrant exclusion of the other. However, both processes are of so much value to the aircraft industry that there would be a decided gain if each found its own application alongside the other.

In general, making photographic prints from a negative is contact printing. If the negative material and the printing paper could be held to close tolerances with varying humidity and temperature, the print would be an accurate reproduction. Contact printing as applied to loft practice is not exactly the same process although it follows the general idea involved. If we have a loft lay-off on ground glass or transparent plastic, we can produce prints therefrom on any sensitized surface by contact printing and by using the loft lay-off as a negative. If we have a loft lay-off on an opaque floor, it is possible to print that lay-off on a sensitized transparent sheet by reflective printing. This sheet when developed can become the negative for further printing.

It will be noted that in this process all printing is done directly with no change in size through photographing or projecting. If we photograph, we can reduce the scale. If we project, we can increase the scale. But, in so doing, we introduce lenses with their disadvantages for the desired degree of accuracy.

Let us make a lay-off of an airplane part on some form of transparent material such as ground glass or plastic. If the lay-off is in

pencil lines, we can print that lay-off on metal, wood, plastic, paper, or tracing cloth by having the surface of the material sensitized. The usual principles applicable to darkrooms, light projection, and photographic chemicals are employed. By making prints on transparent materials, we can increase the number of negatives. By making prints on tracing cloth, we can make blueprints. There are many variations possible, as is readily apparent.

Of course, it is to be noted that any negative, whether it is the original lay-off on plastic or otherwise, must have a low coefficient of expansion to produce a print with a high degree of exactness. Plastics are prepared for pencil lines by sandblasting or sanding. Another type of negative material to use is a transparent plastic that has been made opaque by painting one side. The lay-off is made with a stylus which retrieves the transparency by removing the paint where lines occur. Sharp prints are possible from pencil or stylus tracings.

It is also possible to make a negative from a lay-off made on painted metal or on paper-surfaced metal. Such a negative, which may be glass plate, can be used in the same manner as the plastic negatives referred to above.

By using color filters in the process, it may be possible to make selective prints of various kinds. This matter has not been studied enough for it to be certain that the mold loft can make advantageous use of the process.

The principal advantage in contact printing over the photographic process is that the resulting prints can be held to close tolerances. No lenses or projections being used, there are no errors through distortion. On the other hand, contact printing does not permit scaling a layout, which is possible in the straight photographic process.

The photograph-and-negative method utilizes cameras and projectors in its operation. The part lay-off is made on painted sheet metal or on some other suitable surface. By means of a special camera, we can photograph the lay-off, producing a small-sized negative. The negative is glass to eliminate possible contraction or distortion in developing the negative. After the negative is developed, it can be projected onto a sensitized surface, and a print can thus be produced. Additional prints are made by repeating the projection. By varying the length of projection, scale effect can be introduced at will.

Because this process involves photographing and projection printing, great care must be exercised to produce accurate results. The camera and projector are large. One manufacturer uses a 10-ft. vertically mounted camera. The lens is an F:12.5 with a 14-in. focal length. The negative produced is 14 by 17 in. The camera must be mounted in such a way that it can be moved to the work or the work to it without too much difficulty. The distance from the lens to the work to be photographed must remain stabilized and checked frequently in order to retain a close degree of accuracy in the results. The installation of the camera and work must be made with consideration to the effects of vibrations. Everyone is familiar with the effects of a moving subject in ordinary photography. Our problem is much more serious. The plate negative must be developed by the usual darkroom methods.

By the adaptation of photoengraving methods a camera-projector arrangement permits enlargement of the negative. The manufacturer referred to in the previous paragraph uses an F:16 lens with a 70-in. focal length in the projector. By placing the sensitized sheet on which the print is to be made so as to act as the projector screen the negative can be "blown up" to full scale and printed. Marked lengths, horizontal and vertical, on the original layout carried to the reflection allow for checking the scale before the print is actually made. Unless this is done, there is no assurance that scale errors have been eliminated. By adjusting the relative positions of the lens, negative, and screen, it is possible to make prints to other scales. This is a distinct advantage of this process, for small-scale prints are convenient for record and drafting-room use. The largest print practicable at present is about 5 by 10 ft.

It is usual to print the templet on metal first. Then, without changing the setup, prints are made on tracing cloth prepared for the purpose. Prints are treated chemically as photographic prints in specially prepared tanks of large size. The tracing-cloth print is used in the same manner as any drawing for making vandykes and blueprints.

We come now to the application of photographic reproduction. In this connection, it must be understood that the methods are new to loft practice; for that reason, there may be more extended applications in the future than can be indicated at this time.

Although the pantograph is superior for taking off lines from the body, profile, and half breadth, photographic lifting of lines

may be desirable in some cases. This may be true where basic lines are needed for development and templet making of a part. It also has value where we wish to avoid the tabulation of off-sets. The limitations to the general use of printing where lines are concerned are those of size. Photographic reproduction is not available just yet where sizes greater than 5 by 10 ft. are concerned. Consequently, the lines have to be printed by piecing operations.

Aside from the question of size the use of prints from the loftsman's lines is complicated. There are many construction lines involved in line fairing that would be confusing unless clear distinctions were provided. However, once the lines have been lifted for development and templet making, it is quite simple to use the new layout as a master for prints. This may have advantages where more than one person must work to the same set of lines.

Photographic reproduction finds its place most conveniently in the development of the detail parts and in the templet making for those parts. In using the photographic process, structural drawings from the draftsmen are limited to assemblies and typical arrangements. Details are worked out in the mold loft to full scale so that any layout prepared becomes the drawing as well as the basis for the templet. A full-scale layout for a part having been made, a print on tracing cloth becomes the record for filing, blueprinting, etc. Other prints on metal, wood, plastic, or other material may be used for making tools, gauges, or other special items. Prints made on sheet metal serve as templets or as a ready means for making templets. Prints of corresponding parts may be assembled to become jigs and fixtures for drilling and assembling parts. Where flat assembly jigs are used, as, for instance, in building up a bulkhead, a print can be made on the table flat to become the basis for a sub-assembly jig.

Although the process has not been extensively used for die-making, it seems that prints made directly on the raw material for the die or on templets for the die form are practicable. In this connection, it is to be noted that printing on all sides of a block of material is merely a matter of exposing under control.

In constructing an experimental airplane, it may be desirable to eliminate some of the templet making. In that case, printing may be carried out on the raw material directly. Upon being worked to the information given by the print, the part goes into

construction. Ordinarily, printing on the raw material is of use where the number of parts is limited to single units, although it may also find favor where trial installations are being effected.

Where mock-ups or models of the airplane or a part are required, prints of the layouts concerned can be made on wood. The wood is then formed to the lines and contours shown and becomes a unit in the construction concerned.

Volume production has introduced a need for duplication of templets. This duplication may come from expanding plant requirements, from subcontracting concerns, or from redistribution of functional operations. But, regardless of the cause, increasing the available templets is only simple printing where photographic-reproduction methods are in use.

Sheets to be sensitized can be prepared by the usual gelatinized processes common to the lithographic industry. Another effective method is to use a paper-film lamination now commercially available. In this, the film is transferred from the paper-base support to the metal, wood, or other sheet to be sensitized. This sensitized sheet becomes the printed templet. To allow for changes and alterations after the print is made, the film has a surface that will take pencil lines. Paper-backed film is available in sheets up to about 3 ft. wide.

Gelatin products and most of the plastics are affected by humidity and temperature changes. Caution in their use by the loftsman is required. Any new adaptations to practices followed in the loft where these substances are used should be done with an experimental approach. Modern chemistry will give solutions if they are sought carefully.

In contact printing, diffusion of lines will occur if the line to be printed is too far from the sensitized sheet. This occurs when the plastic sheet used as a negative is too thick. Sheet not over 0.025 in. in thickness has been known to give good results. Here, again, an experimental approach is necessary.

The use of X-ray photograph has been reported as a method for making contact prints. The lay-off is made on a metal sheet that has been coated with a material that will fluoresce when under X-rays. By placing a negative plate or film in contact with the lay-off and by exposing the combination to X rays, a print is made on the negative plate or film. This negative can be used to produce prints by the ordinary methods.

A method of reproduction used in the silk-screen industry will be described briefly, for it uses the stencil process which may lead to further applications in the loft. In this process, a form of tracing, paper-backed by a lacquer film, serves as the basis of the operation. This paper-backed film is laminated so that the film can be transferred by gluing to another surface.

If we have a full-scale lay-off on the floor, we can trace it to the special paper described above. Special tools allow for cutting away the film to follow the trace without cutting the paper backing. Upon completion of the tracing, the film is glued or lacquered to a silk screen stretched on a rack—the film side toward the silk. By breaking the lamination of the paper back, we can remove the paper, leaving the film stencil on the silk screen.

The silk screen becomes the stencil. Prints are made by painting through the screen; a squeegee removes excess paint.

If the laminated paper film had been made with a gelatin-base film sensitized to light, we should be able to photograph on the paper-film combination. This would give a photographic stencil.

This process uses an interesting material—laminated paper film —suitable to special applications in the loft. If the layout of a part is on the loft floor, there are two methods for making a lift from the floor to the paper film. One is by tracing and then transferring the film to the metal templet directly. The other is to use a sensitized film, photograph the lay-off, and then transfer the film to the metal, wood, paper, or other surface to be used as a templet. It has been stated that such a templet can stand reasonable wear.

Photographic reproduction has given an interesting impulse to a series of processes that may result in fewer steps between the drawing and the templet. Consider the following for the moment: Produce a scale drawing on a transparent material that is insensitive to temperature and humidity. Project the drawing for printing to any desired scale with accuracy. Make prints on paper or on templet material as desired. If such procedures could be followed, we should have reached a high degree of efficiency in producing and reproducing lay-offs.

Conclusion. A review of this study of airplane lofting will reveal that the work done in the loft to fair the airplane shape and the work done to expedite the making of airplanes are compatible. Expanding loft consciousness to include a more vivid

awareness of the actual making of parts and their assembly into airplanes seems logical and practical. The construction of models, mock-up, forms, patterns, templets, and assembly jigs by the loftsman-trained man can result in the elimination of some unnecessary steps. A further benefit will follow where the loftsmen can follow through on some assemblies of prototype airplanes to see that form, shape, size, and fit of parts and of sub-assemblies are practicable.

The loftsman approaches the detail draftsman in his understanding of construction. He carries the subject of making the airplane a step beyond the drafting room. With the possibilities inherent in newer methods, he can serve a useful function in covering the gap between the detail designer and the shop mechanic. It may be possible that this liaison could lead to a means for eliminating some of the steps between the small-scale drawing of the designer and the actual airplane part of the shop mechanic, without incessant trial-and-error procedures and without misfits and misalignments.

Some effort has been expended in explaining laying off of the airplane according to the methods common to the industry. In addition, much has been said regarding the newer methods. Owing to the transition taking place, it will be necessary for the loftsman to be vigilant with respect to his ability to serve usefully. The newer methods prescribe a technique not common to laying off as taught some years ago. But the loftsman's training and experience are essential to the functions concerned in constructing airplanes. Coordinating parts of the airplane to a fit with each other and with the whole can be achieved solely by the care and accuracy shown in the templets from which parts are made. And, further, diligent attention to the avoiding of interferences is the contribution of the man in the loft who has studied the structure in full scale, with the third dimension in mind throughout his consideration of the problem.

Although mechanical and photographic reproduction present possibilities in the way of new tools, they do not provide the brain needed for remembering and reasoning. At best, the airplane is complicated. Much goes into little space. The manufacturer cannot await the assembly before lifting parts. Nor is there need for that. The loftsman matches templets and he lays off his lines with a view to all the factors entering the matter so that assembly

of the airplane is true to the design, fair in shape, and with space equitably divided.

The first few airplanes assembled are the criterion for the remainder. It behooves the loftsman to check assembly jigs and the assembly of parts therein until everything has been proved. In carrying out the operation, the maintenance of alignment and the certainty of fairing are the most important. Where check dimensions can be made on the over-all length, width, etc., it is considered to be effective insurance. Forms, jigs, and templets requiring modification to give absolutely correct results should be changed to suit assembly after a check of the lay-off has been made as to the cause for the discrepancies. There is no complete system that will eliminate all the unknowns in laying off an airplane. Likewise, there is no reason for the loftsman to assume that the prototype airplanes will be satisfactory without his assistance in checking for omissions and errors.

Practical checking begins when parts go into sub-assemblies and finishes when the completed airplanes come off the assembly lines in quantities. The loftsman views the trial flights of an airplane with a degree of satisfaction commensurate with the accuracy of his work. He can appreciate the unspoken "Well done" that comes from a craft that flies easily.

In review, it might be said that the loftsman's understanding of the laying off of the airplane is centered in his ability to cope with the geometry of the craft. Each circumstance and each problem presented are based on understanding lines in space. The intersection of these lines and surfaces can be visualized by the trained individual with accuracy and facility; such visualization is the loftsman's forte.

A great many practical tricks of the loftsman's trade will come through experience on the loft floor. Each loft has its own special group, and each loftsman has his own special methods. The student is cautioned to watch carefully and to analyze diligently, to garner unto himself those features essential to a better understanding of his profession.

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